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DOCUMENTATION AND ANALYSIS OF THE

WSEG-10 FALLOUT PREDICTION MODEL.

THESIS

AFIT/GNE/PH/80M-2

Dan W. Hanifen

CAPT USAF

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AFIT/GNE/PH/80M-2

DOCUMENTATION AND ANALYSIS OF THE WSEG-10 FALLOUT PREDICTION MODEL

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Nuclear Engineering

by

Dan W. Hanifen, B.S.

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March 1980

Approved for public release; distribution unlimited

Preface

This independent study began as an effort to recreate and document the most widely used analytical fallout code, WSEG-10. Specifically, local access to this model in computer coded form will provide a basis for further fallout studies at the Air Force Institute of Technology. Additional analyses of the crossrange dispersion term (σ_y) and model conservation of activity were also performed. All computer work was done using the ASD CYBER 74 computer at Building 640.

This author gratefully appreciates the guidance provided by Dr. C. J. Bridgman, thesis advisor, to accomplish this independent study. Thanks are also extended to Mr. Ralph Mason, National Military Command Support Center, for providing the most recent computer coded version of WSEG-10 along with sample results. Special thanks are also extended to my wife for her patience through this independent study and her assistance preparing this document.

Dan W. Hanifen

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Abstract

The purpose of this independent study is to recreate and document the most popular analytical fallout model in use over the past twenty years, WSEG-10. Local access to WSEG-10 at the Air Force Institute of Technology, School of Engineering, will provide a basis for future fallout studies. As such, this study provides a fully documented Fortran computer code containing the most recent version of the WSEG-10 analytical model with sample output. To further understand this computer code, a general discussion of the WSEG-10 fallout model and analysis of crossrange dispersion (σ_y) and activity conservation is included. Results of the analysis of σ_y demonstrate that diffusive growth is not accounted for in the model and that crosswind shear is the dominant, long term effect. In a comparative conservation analysis, the WSEG model in use today does not conserve activity due to the unnormalized character of the crossrange transport function. This effect is substantial at yields less than .1 MT. Activity not conserved varied between 31.4% at 1 KT and a wind of 60 st. mi. to less than 1% at 100 MT and winds of 60 st. mi. Also included is a further discussion of model limitations or inconsistencies discovered either through computer use during this independent study or during initial literature search.

DOCUMENTATION AND ANALYSIS OF THE
WSEG-10 FALLOUT PREDICTION MODEL

I. Introduction

This thesis examines the most popular analytical fallout prediction model in use over the past twenty years — WSEG-10. The specific purpose of this thesis is to recreate and document a working copy of the latest computer coded version of WSEG-10 (hereafter referred to as WSEG). Local access of WSEG will provide a basis of comparison for future fallout modeling at the Air Force Institute of Technology (AFIT).

As such, the topics presented in this thesis are:

1. A description of the analytical relationships comprising the basis of the WSEG model.
2. An analysis of crossrange dispersion (σ_y).
3. An analysis of conservation of activity using the WSEG model.
4. Computer implementation using Fortran computer language and the ASD CYBER 74 computer.
5. A discussion of WSEG model limitations and shortcomings.

The most recent version of the WSEG model in the form of a coded Fortran subroutine and sample results were supplied by Mr. Ralph Mason, National Military Command Support Center. The subroutine and results are contained in Appendix A.

Since WSEG is based on empirical approximations, derivations of the basic mathematical relationships is often impossible. The following chronology is provided as background to the evolution of WSEG.

Background

After the Mike nuclear test of the Ivy Series in October of 1952, the Rand Corporation was contracted to begin nuclear fallout studies (Ref. 6:6). Rand produced several fallout prediction techniques beginning with a hand-calculated "Disk-tosser" model which was eventually converted to computer solution. This early attempt was both complex and time consuming. It divided the nuclear cloud into many stacked disks, each of which were transported independently. The experimental data base was poor and not properly documented. The experimental data was available but depended on such a number of parameters (yield, height of burst, wind condition, shear and soil) that generalizations were difficult if not impossible. As nuclear testing continued, the complexity and cost to refine and operate this model grew along with the data base.

As results became reliable, a second technique was developed by Rand to eliminate the costly, time consuming, machine calculations. This technique used analytical approximations to the complex "Disk-tosser" model. These, in effect, considered the nuclear cloud homogenous and "smeared" the fallout on the ground according to the initial parameters of yield, wind, shear, height of burst and soil conditions. The

resulting empirical model (RM 2460) used a log-normal activity size distribution with a mean of 44 microns, a standard deviation of 2 microns, the $t^{-1.2}$ (Way-Wigner) decay law, and assumed 80% of the activity is deposited locally (Ref. 13). They also calculated a function $\psi'(T)$ representing the fractional rate of activity deposition everywhere as a function of particle fall time (T). Rand did not assign $\psi'(T)$ a single functional type, although when plotted versus T, the curve resembled a log-normal distribution function (Refs. 10:36-40; 4:30). The concept appeared promising, but the empirical model generated by Rand was never popular (Ref. 6:13).

In the late 1950's, the Weapons System Evaluation Group (WSEG) sought to create an *inexpensive*, *easy to use*, *analytical* fallout prediction code of their own. It was published in 1959 (Ref. 1). The authors, Pugh and Galiano, incorporated Rand data for particle size distribution and particle fall rates into their original model (Ref. 1:27). They also adopted or rediscovered the Rand $\psi'(T)$, calling it "g(t)". The WSEG "g(t)" represents the normalized fractional rate of activity deposition everywhere as a function of time. It was arbitrarily assigned a negative exponential form which empirically fit the Rand data everywhere but at very early times (Ref. 6:13). In 1960 the exponent of "g(t)" was modified to improve low yield capability (Ref. 2). In 1962, a National Academy of Sciences committee revised the WSEG model to its

present form (Ref. 10). These modifications made the model more closely conform to the experimental data collected during the extensive nuclear testing of that decade.

A detailed explanation of the current form of WSEG is contained in the next section.

II. WSEG

As stated earlier, WSEG is an empirical approach to local fallout prediction based upon early nuclear test data. It is designed to provide reliable fallout prediction for yields between 1 KT and 100 MT. All activity for deposition is assumed within the fallout cloud and 80% is assumed deposited locally. WSEG neglects the induced activity of the stem created by torroidal circulation during the cloud rise in early times after the burst.

The version used for this thesis assumes a land-surface burst. No adjustments are made to account for burst heights greater than zero.

In order to present a description of WSEG in some logical order, the model will be defined within a chronology of events for a nuclear burst beginning with nuclear cloud formation.

The cloud is initially formed because the nuclear fireball vaporizes both the surface of the earth at ground zero and the weapon itself. The activity contained in the cloud is both neutron induced and fission. After formation, the fireball rises and begins to cool at its outer edges faster than the center thereby creating the typical torroidal currents associated with the nuclear cloud. WSEG arbitrarily assumes that the cloud will rise to a maximum center height within fifteen minutes and then stabilize. This stabilized cloud is modeled as a right circular cylinder as in Figure 1.

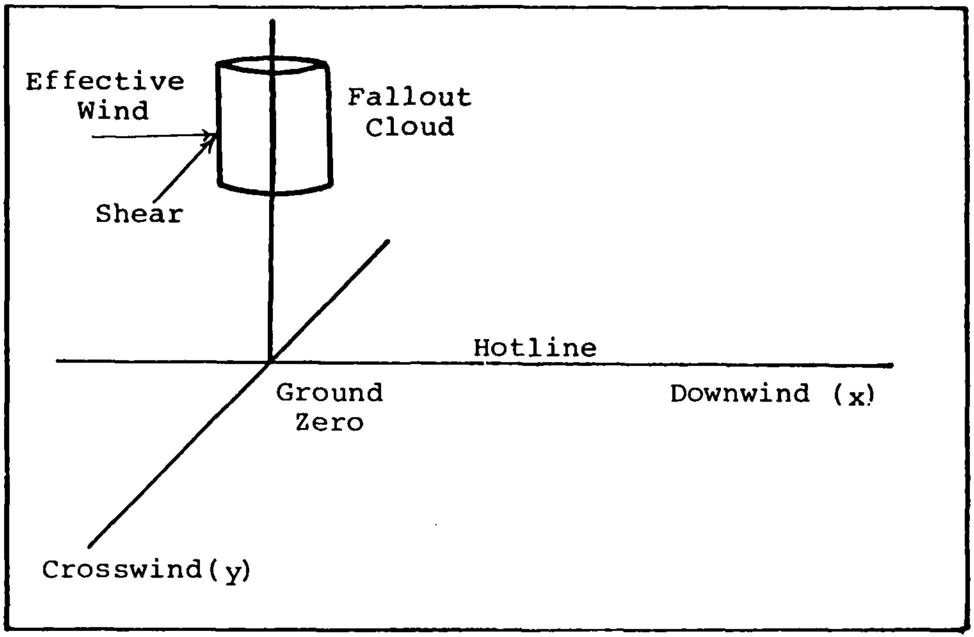

Figure 1. Fallout Cloud Model

At this point, the cloud dimensions and altitude are fixed as reference values. Cloud center height (kilofeet) is given by WSEG as:

$$H_c = 44. + 6.1 \ \ell n(\text{yield}) - .205 \ |\ell n(\text{yield}) + 2.42| \ (\ell n(\text{yield}) + 2.42)^* \qquad (1)$$

The radioactivity in the stabilized cloud is assumed to be normally distributed in both the vertical and horizontal directions, namely

$$\rho(x,y,h) = \frac{\exp -\frac{1}{2}\left[\frac{x^2 + y^2}{\sigma_o^2} + \frac{(h - H_c)^2}{\sigma_h^2}\right]}{(2\pi)^{3/2} \ \sigma_o^2 \sigma_h} \qquad (2)$$

*Unless otherwise stated, yield has units of megatons (or MT).

where x and y are distances in the downwind and crosswind directions respectively and h is the height above ground in kilofeet. WSEG defines σ_o and σ_h as

$$\sigma_o(\text{st.mi.}) = \exp(0.70 + \frac{\ln(\text{yield})}{3} -$$
$$3.25/(4.0 + (\ln(\text{yield}) + 5.4)^2)) \tag{3}$$

and

$$\sigma_h(\text{kilofeet}) = .18\ H_c \tag{4}$$

WSEG further defines the dimensions of the stabilized cloud where the cloud diameter is $4\sigma_o$ and the vertical thickness is $4\sigma_h$.

Independent of this spatial distribution, the radioactivity is distributed on different sized particles by some *activity/size distribution*, A(r). As stated earlier, this activity/size distribution is based on Rand data and defined as:

$$A(r) = \frac{\exp-\frac{1}{2}\left(\frac{\ln(\bar{m}) - \ln(r)}{\beta}\right)^2}{\sqrt{2\pi}\ \beta r} \tag{5}$$

where $\bar{m}$ = (44 microns)
r = (particle radius in microns)
β = .690

As time increases, the cloud will expand and move horizontally and fall vertically towards the earth as fallout deposition occurs. WSEG assumes upward expansion is zero. This horizontal motion is due to three forces assumed acting on the cloud.

The first force is torroidal circulation which at early times causes the fallout particles to be swept toward the center of the cloud. The resulting fallout pattern is compressed around ground zero such that the effective radius of the pattern is one-half of the actual radius of the cloud. Although not explicitly stated within Reference 1, torroidal circulation is the dominant effect at early time. This effect lessens as torroidal circulation decreases over time thereby allowing the cloud to grow radially. WSEG arbitrarily uses three hours as the cutoff for any torroidal effect.

The second force acting on the cloud is effective wind (Wind). WSEG used a single effective wind vector over the vertical extent of the cloud. The net effect is to translate the fallout cloud downwind. Winds used to validate the original model vary between 0 and 60 knots.

The third force is shear (S_c) which WSEG assumes is constant over the vertical extent of the cloud. It is the change in direction of the effective wind vector horizontally as a function of altitude. Vertical shear is neglected. The shear used varies between .1 and .6 knots/kilofeet. The effect of the shear is to expand the cloud and spread out the fallout pattern as one would open a fan.

The combined effects of torroidal circulation, effective wind, and shear are accounted for within the terms describing downwind (σ_x) and crosswind (σ_y) dispersion. The function σ_x is affected by the effective wind and defined as:

$$\sigma_x^2 (\text{st.mi.})^2 = \sigma_o^2 \frac{(L_o^2 + 8\sigma_o^2)}{L_o^2 + 2\sigma_o^2} \tag{6}$$

where $L_o = \text{Wind} \cdot T_c$

and $T_c = \text{Time Constant} =$

$$1.0573203((\frac{12}{60})H_c - 2.5(\frac{H_c}{60})^2)(1 - .5 \exp-(\frac{H_c}{25})^2) \tag{8}$$

and σ_o is defined by Equation (3). Wind, torroidal growth, and shear all affect σ_y which is defined as

$$\sigma_y^2 (\text{st.mi.})^2 = \sigma_o^2 + \frac{1}{L} (8|x + 2\sigma_x|\sigma_o^2) +$$

$$\frac{2}{L^2}(\sigma_x T_c \sigma_h S_c)^2 + \frac{1}{L^4}((x + 2\sigma_x)\ L_o T_c \sigma_h S_c)^2 \tag{9}$$

where σ_o and σ_h are defined by Equations (3) and (4) respectively, S_c is the crosswind shear and

$$L^2 = L_o^2 + 2\sigma_x^2 \tag{10}$$

Thus, σ_x is fixed by initial cloud parameters and effective wind while σ_y will vary with time. This is discussed in depth in the next chapter.

Throughout the growth and transport of the radioactive cloud there is a continual fall of particles back to the ground. As mentioned in the Background, WSEG states that there must be some function "g(t)" which describes the fractional rate of activity arrival on the ground everywhere at

some time t. The integral of this function, G(t), represents the fraction of activity down at time t where

$$G(t) = \int_0^t g(t')\, dt' \qquad (11)$$

This g(t) function will be independent of the horizontal activity distribution and therefore independent of the growth of σ_y with time. On the other hand g(t) will be dependent on the initial vertical distribution and the activity/size distribution which determines particle fall rate.

This activity deposition, g(t), is assumed in the original WSEG document without derivation as

$$g(t) = \frac{F \exp - \left(\frac{t}{T_c}\right)^{n_o}}{T_c\ \Gamma\left(1 + \frac{1}{n_o}\right)} \qquad (12)$$

where

$$T_c = \text{Time Constant}$$

$$n_o = 1.5 - .25\left(\frac{H_c}{60}\right)^2 \qquad (13)$$

$$F \simeq 1.0$$

This arbitrary choice of g(t) is based on Rand calculations which assume an activity/size distribution given by Equation (5). These calculations are neither shown nor referenced in the original WSEG model contained in Reference 1. If the activity/size distribution for a given set of initial conditions is different than that given by Equation (5), the form of g(t) should change. This is not possible

under the WSEG model where the function g(t) is fixed as Equation (13). The only possible compensation for various activity/size distributions results because T_c varies with yield (Ref. 2).

After modifications in 1962,

$$g(t) = \frac{F \exp - \left(\frac{t}{T_c}\right)^n}{T_c \; \Gamma(1 + \frac{1}{n})} \qquad (14)$$

where $$n_o = F = 1.0$$

and $$n = \frac{n_o L_o{}^2 + \sigma_x{}^2}{L_o{}^2 + .5\sigma_x{}^2} \qquad (15)$$

The function g(t) can be transformed to a downwind distance function since

$$g(t)dt = g(x)dx$$

and $$x = \text{Wind} \,.\, t$$

The downwind distance, x, is substituted into Equation (14) for t as:

$$g(x) = \frac{\exp - \left(\frac{t \,.\, \text{Wind}}{T_c \,.\, \text{Wind}}\right)^n}{T_c \,.\, \text{Wind} \,.\, \Gamma(1 + \frac{1}{n})} \qquad (16)$$

or $$g(x) = \frac{\exp - \left(\frac{x}{L_o}\right)^n}{L_o \; \Gamma(1 + \frac{1}{n})} \qquad (17)$$

To provide continuity in a "0" wind environment near ground zero WSEG replaces L_o with L and the domain is arbitrarily extended by setting $x = |x|$. Therefore the final activity deposition function in terms of distance is:

$$g(x) = \frac{\exp-\left(\frac{|x|}{L}\right)^n}{L\,\Gamma\left(1 + \frac{1}{n}\right)} \tag{18}$$

g(x) in this form also represents the fallout deposition distribution function used within WSEG.

In order to predict upwind fallout and at the same time preserve normalization, a function ϕ is empirically inserted where

$$\phi = \int_{-\infty}^{w} \frac{1}{\sqrt{2\pi}} \exp(-\tfrac{1}{2}z^2)\,dz \tag{19}$$

and $$w = \left(\frac{L_o}{L} \cdot \frac{x}{\sigma_x \alpha_1}\right)$$

The normalized downwind and upwind distribution is then represented as:

$$\phi\left(\frac{L_o}{L} \cdot \frac{x}{\sigma_x \alpha_1}\right) \cdot g(x) \tag{20}$$

where $$\int_{-\infty}^{\infty} \phi\left(\frac{L_o}{L} \cdot \frac{x}{\sigma_x \alpha_1}\right) \cdot g(x)\,dx = 1$$

The model forces ϕ to behave as follows:

$$.5 \leq \phi \leq 1. \text{ for } x \geq 0.$$

$$0. \leq \phi \leq .5 \text{ for } x \leq 0.$$

α_1 is an adjustment factor to reduce the area covered by fall-out prior to cloud stabilization due to torroidal compression (Ref. 4:35) and is defined as:

$$\alpha_1 = \frac{1}{\dfrac{(1 + .001 \cdot H_c \cdot \text{Wind})}{\sigma_o}} \tag{21}$$

where σ_o is defined by Equation (3).

The parameter "n" defined by Equation (15) and used as the exponent in g(x) and g(t), is plotted in Figure 2 for yields of 1, 10, 100, 1000 and 10,000 KT. As seen, "n" is a weak function of yield and varies dramatically for winds between 0 and 1 $\frac{\text{st.mi.}}{\text{hr}}$. However, for all intents and purposes, the variation can be described as:

$$n = 2 \text{ when Wind} \approx 0$$

$$n \approx 1 \text{ when Wind} > 0$$

Figures 3 and 4 depict g(x) and ϕ.g(x) for a 1 MT burst. Figure 3 represents the case where the effective wind and shear are both 0 while Figure 4 represents the behavior of g(x) and ϕ.g(x) where the effective wind is 10 $\frac{\text{st.mi.}}{\text{hr}}$ and shear is 0. If plotted further downwind g(x) and ϕ.g(x) would asymptotically approach 0. The validity of the substitution $\int_{-\infty}^{\infty}\phi . g(x)dx = 1$ for $\int_{0}^{\infty}g(x)dx = 1$ is addressed in Section IV concerning conservation of activity. Numerical integration was used to integrate g(x) and ϕ.g(x) and as such finite integration limits were established as an approximation.

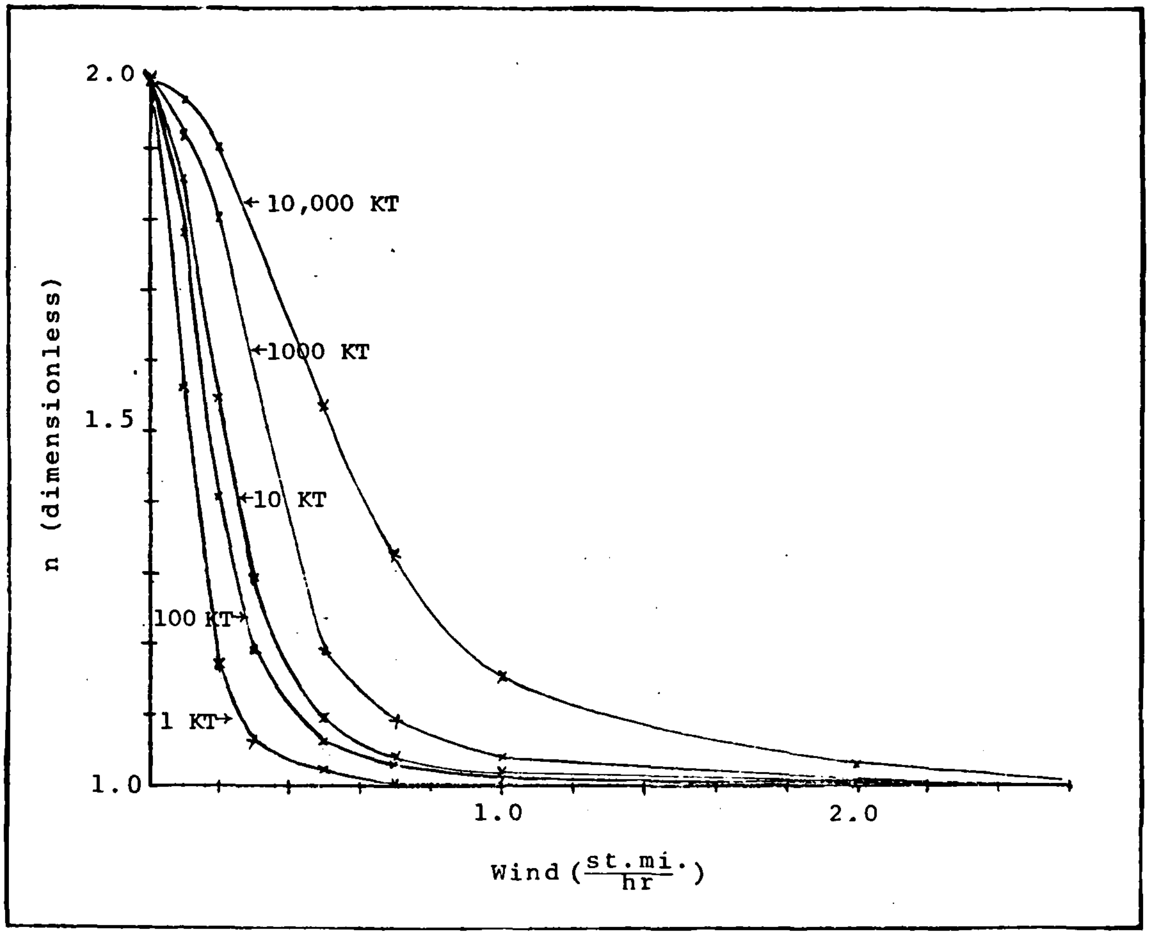

Figure 2. Parameter "n" vs. Wind

The downwind transport function f_x can now be written as:

$$f_x = \text{Yield} \cdot \text{SNC} \cdot \phi \cdot g(x) \cdot \text{fission fraction} \qquad (22)$$

where SNC is the Source Normalization Constant =

2×10^6 Roentgens/hr/MT/(st.mi.)^2

The crosswind transport function is a modified Gaussian distribution of the form:

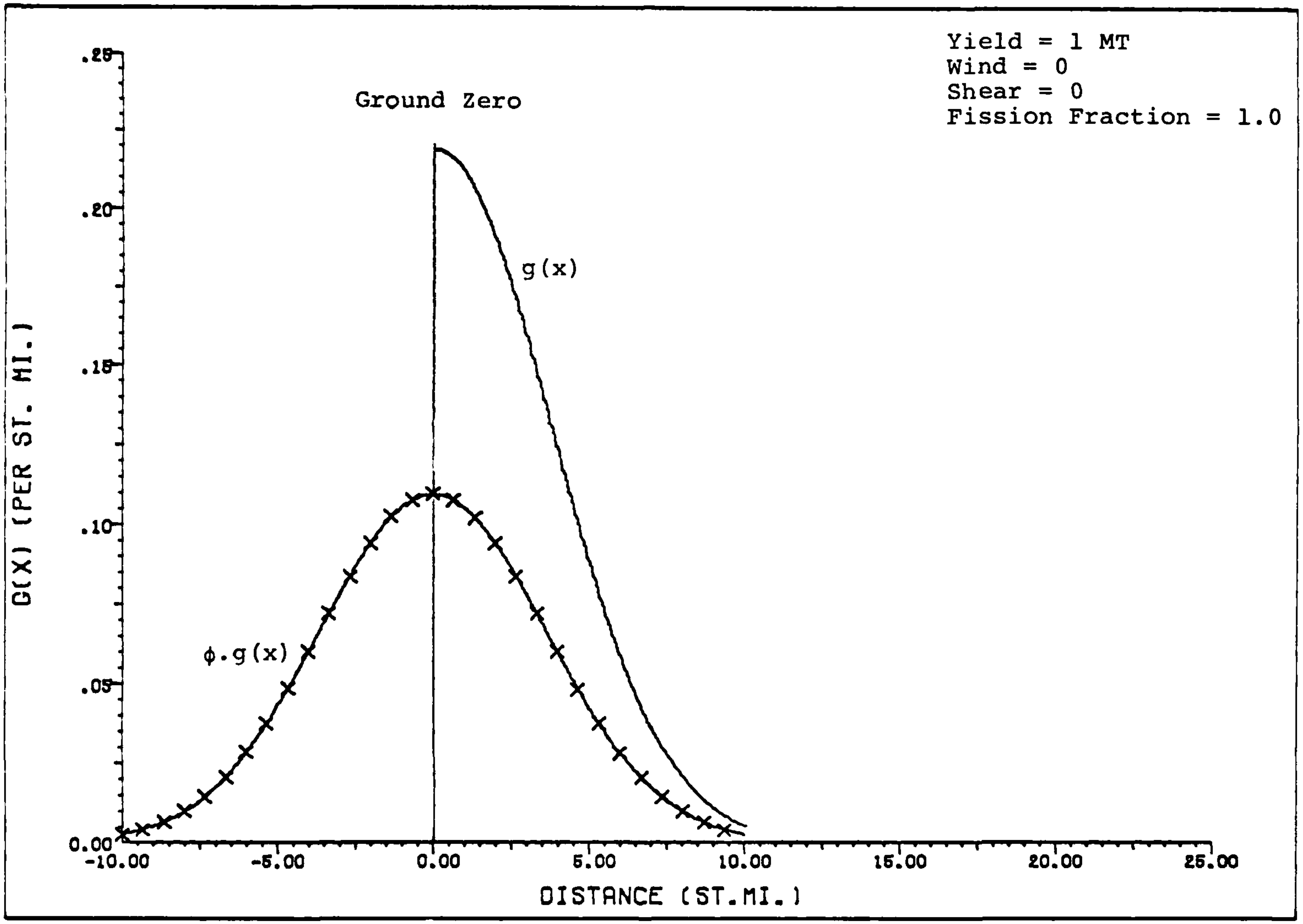

Figure 3. $g(x)$ and $\phi . g(x)$ vs. Distance

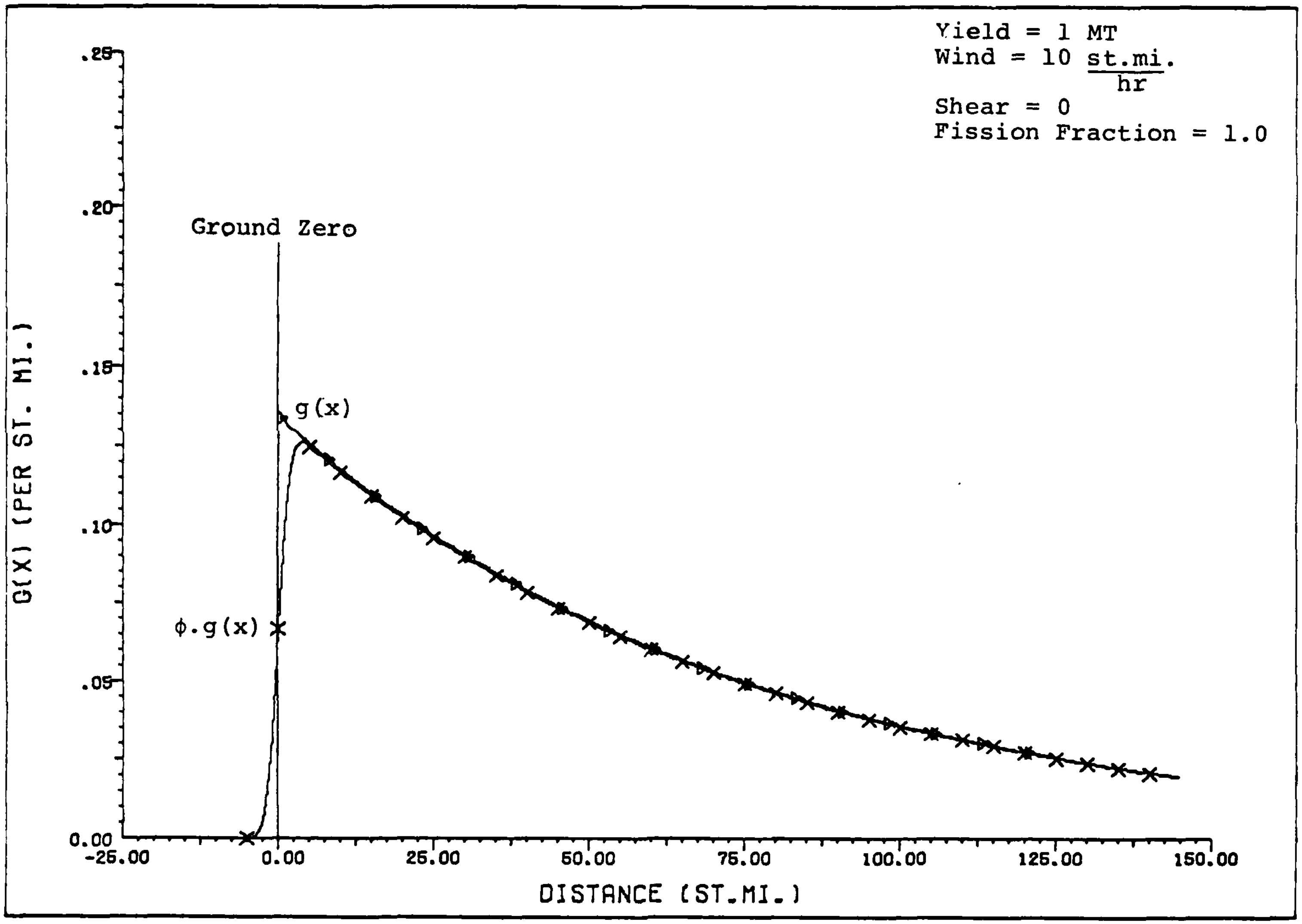

Figure 4. g(x) and ϕ.g(x) vs. Distance

$$f_y = \frac{\exp -\frac{1}{2}\left(\frac{y}{\alpha_2 \sigma_y}\right)^2}{\sqrt{2\pi}\ \sigma_y} \tag{23}$$

where α_2 is an adjustment factor added in 1962 similar to α_1 but only effective for 2 hours (Ref. 4: 36). It is defined as:

$$\alpha_2 = \frac{1}{\left(1 + \frac{.001 \cdot H_c \cdot \text{Wind}}{\sigma_o}\right)\left(1 - \phi\left(\frac{2x}{\text{Wind}}\right)\right)} \tag{24}$$

The activity of the fallout in the cloud decays by Way-Wigner ($t^{-1.2}$) as already mentioned, as does the fallout deposited. This assumes no fractionation. WSEG creates iso-dose rate contours by utilizing the Unit Time Reference Dose Rate (D_{H+1}) which is the product of the downwind and cross-wind transport functions ($f_x \cdot f_y$). D_{H+1} represents the activity at some point (x,y) one hour after detonation. This includes all activity that has arrived at (x,y) in 1 hour plus all activity that will be deposited. These contours are elliptical with the major axis along the hotline. The length of the contour depends on the initial yield of the weapon and on the magnitude of the effective wind vector. Contour width is determined primarily by shear (see Section III).

To obtain a measure of dose to humans, "Biological Dose" was defined as the product of the D_{H+1} and a conversion factor, called Bio. Bio is an empirical function depending on fallout arrival time and length of exposure. Ten percent of

the dose received is assumed irreparable and ninety percent is assumed reparable with a thirty day time constant (Ref. 11). Mathematically this set of conditions is written as:

$$D(t) = 10\% \int_{t_a}^{t} D_{H+1}\tau^{-1.2}\, d\tau +$$

$$90\% \int_{t_a}^{t} D_{H+1}\tau^{-1.2} \exp\left(\frac{1}{K}(t-\tau)\right) d\tau \qquad (25)$$

where K = 30 days and t_a = average expected time of arrival of the fallout and is defined as:

$$t_a = \left(0.25 + \frac{L_o^2 (x + 2\sigma_x^2) T_c^2}{L^2 (L_o^2 + .5\sigma_x^2)} + \frac{2\sigma_x^2 T_1^2}{L_o^2 + .5\sigma_x}\right)^{\frac{1}{2}} \qquad (26)$$

This equation assumes the earliest arrival time of fallout anywhere is .5 hours. T_1 equals one hour and is included to maintain dimensionality. It is often eliminated from the expression. At large x Equation (26) reduces nicely to $t_a \simeq \frac{x}{\text{Wind}}$.

Equation (25) was solved numerically and plotted as Dose vs. Time. Bio was then approximated in Reference 1 as:

$$\text{Bio} = (t/19)^{-.33}$$

so that the dose at some time after activity arrival is defined as:

$$\text{Dose} = D_{H+1} \cdot \text{Bio}$$

Further refinements in the model resulted in a second order approximation for Bio of the form:

$$Bio = \exp-(.287 + .52\ln(\frac{t_a}{31.6}) + .04475\ \ln(\frac{t_a}{31.6})^2) \qquad (27)$$

which is in use today.

These special conditions dictated the necessity for the definition of a special unit of dose, the ERD. The ERD or Equivalent Residual Dose, actually has units of Roentgens even though it pertains to human whole-body damage. This is not in keeping with the current philosophy in assigning units of exposure and dose. This use of Roentgens as a measure of dose instead of exposure tends to confuse those new to WSEG. The subroutine contained in Appendix A refers to the original Pugh definition of dose. The AFIT version contained in Appendix B generates only dose rate contours. Conversion to the proper units will be necessary if dose contours are required in the future.

III. Crossrange Dispersion

This section will examine the crossrange dispersion (σ_y) of the fallout cloud by developing the terms in its definition. The specific purpose of this analysis is to determine whether wind shear or torroidal growth is the most significant contributor to crossrange dispersion. Also an examination of the resemblance between the form of the torroidal growth term and diffusive growth according to Fick's Law is included.

Recall $\sigma_y{}^2$ is defined by Equation (9) as:

$$\sigma_y{}^2 = \sigma_o{}^2(1 + \frac{8}{L}|x + 2\sigma_x|) + \frac{2}{L^2}(\sigma_x{}^2 T_c{}^2 \sigma_h S_c{}^2) +$$

$$\frac{1}{L^4}((x + 2\sigma_x)\ L_o T_c \sigma_h S_c)^2 \qquad (9)$$

This discussion will first consider the contribution to crossrange dispersion by shear represented by the second and third terms of Equation (9). The first term expressing torroidal growth is discussed later in this section.

To begin with, the second term of Equation (9) was added to the WSEG model without derivation or reference as an afterthought to reduce the fallout concentration near ground zero using shear (Ref. 10). Little more can be said about its development. In fact, its total contribution to σ_y is small considering the remaining shear term.

This remaining shear term represents the original shear contribution to σ_y that Pugh and Galiano postulated, modified

without reference or derivation for better response near ground zero for low winds (Ref. 1 :14). The term can easily be transformed to the original form in Reference 1 which is $(S_c \sigma_h \frac{x}{\text{Wind}})^2$. The following derivation will utilize this early form and will consider shear as the sole contributor to crossrange dispersion, or $\sigma_y = S_c \sigma_h \frac{x}{\text{Wind}}$. This discussion is taken from pp. 10-35 of the original WSEG document to derive the expression (Ref. 1). WSEG assumes that effective wind is the average of all wind vectors through which the fallout particles travel to earth.

This effective fallout wind is defined as:

$$\text{Wind} = {}_h\int^o \frac{W(h)}{V(h)} dh \Big/ {}_o\int^h \frac{1}{V(h)} dh \qquad (28)$$

where W(h) is local wind at altitude h and V(h) is the rate of fall of a typical particle at altitude h_o. Since the wind data is obtained at discrete altitudes it can also be represented as:

$$\text{Wind} = \frac{\sum_{i=1}^{n} \tau_i W(i)}{\sum_{i=1}^{n} \tau_i} \qquad (29)$$

where τ_i = time spent within each wind layer by a typical particle falling to earth and W(i) is the wind in the i^{th} layer.

WSEG further assumes that the effective wind is a slowly varying vector dependent upon altitude which can be expanded around cloud center height as a Taylor series for both

crosswind (W_y) and downwind (W_x) components:

$$W_x = W_{x_{h_o}} + \left(\frac{dW_x}{dh}\right)_{h_o} (h - h_o) + \tfrac{1}{2}\left(\frac{d^2W_x}{dh^2}\right)_{h_o} (h - h_o)^2 + \ldots$$

$$W_y = 0 + \left(\frac{dW_y}{dh}\right)_{h_o} (h - h_o) + \tfrac{1}{2}\left(\frac{d^2W_y}{dh^2}\right)_{h_o} (h - h_o)^2 + \ldots$$

with Downwind Shear $= S_x = \left(\frac{dW_x}{dh}\right)_{h_o} \quad \left(\frac{\text{st.mi.}}{\text{hr-kilofeet}}\right)$

Crosswind Shear $= S_c = \left(\frac{dW_y}{dh}\right)_{h_o} \quad \left(\frac{\text{st.mi.}}{\text{hr-kilofeet}}\right)$

The higher order terms are neglected as they are assumed small. WSEG also assumes downwind shear is neglected.

Finally $S_c \cdot \sigma_h$ = magnitude of wind vector direction change over 1 standard deviation in altitude and the total contribution to σ_y is $S_c\sigma_h t$, where "t" is time after burst in hours and defined as $\frac{x}{\text{Wind}}$. Pugh and Galiano recommend using shear evaluated for layers to two to four σ_h above and below H_c for best results (Ref. 1:24). Figure 5 demonstrates how the shear affects σ_y assuming the cloud is modeled as a cylinder with a radius equal to the radius of the cloud.

Figures 6-8 show that wind shear contributes significantly at later times. These figures depict σ_y^2 versus time for several shear and wind conditions. The two terms representing a shear contribution were combined into one curve and included on the same graph. The torroidal growth term was also included as a separate curve. All curves

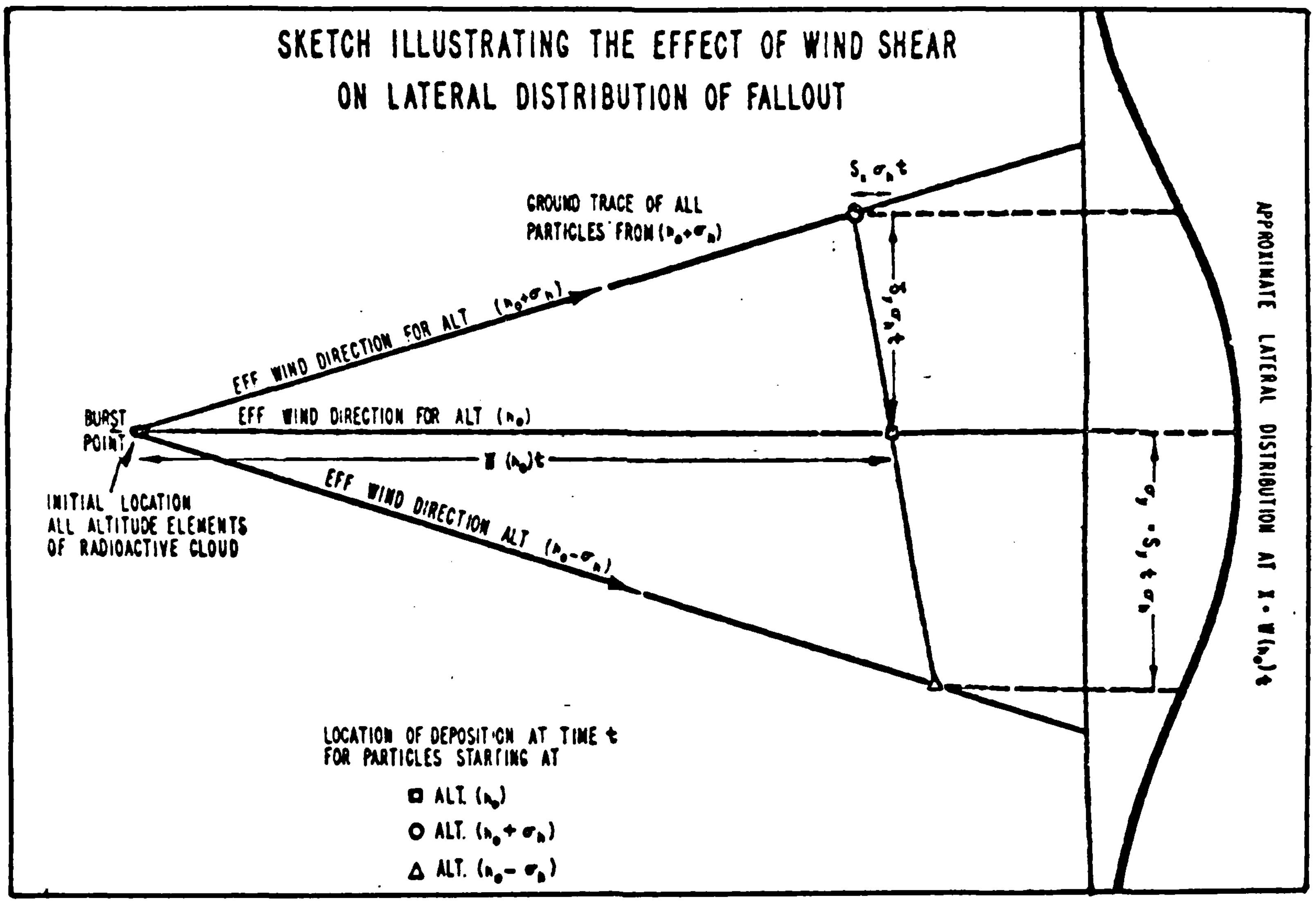

Figure 5. Effect of Wind Shear on Lateral Distribution of Fallout (Ref. 1, p. 12)

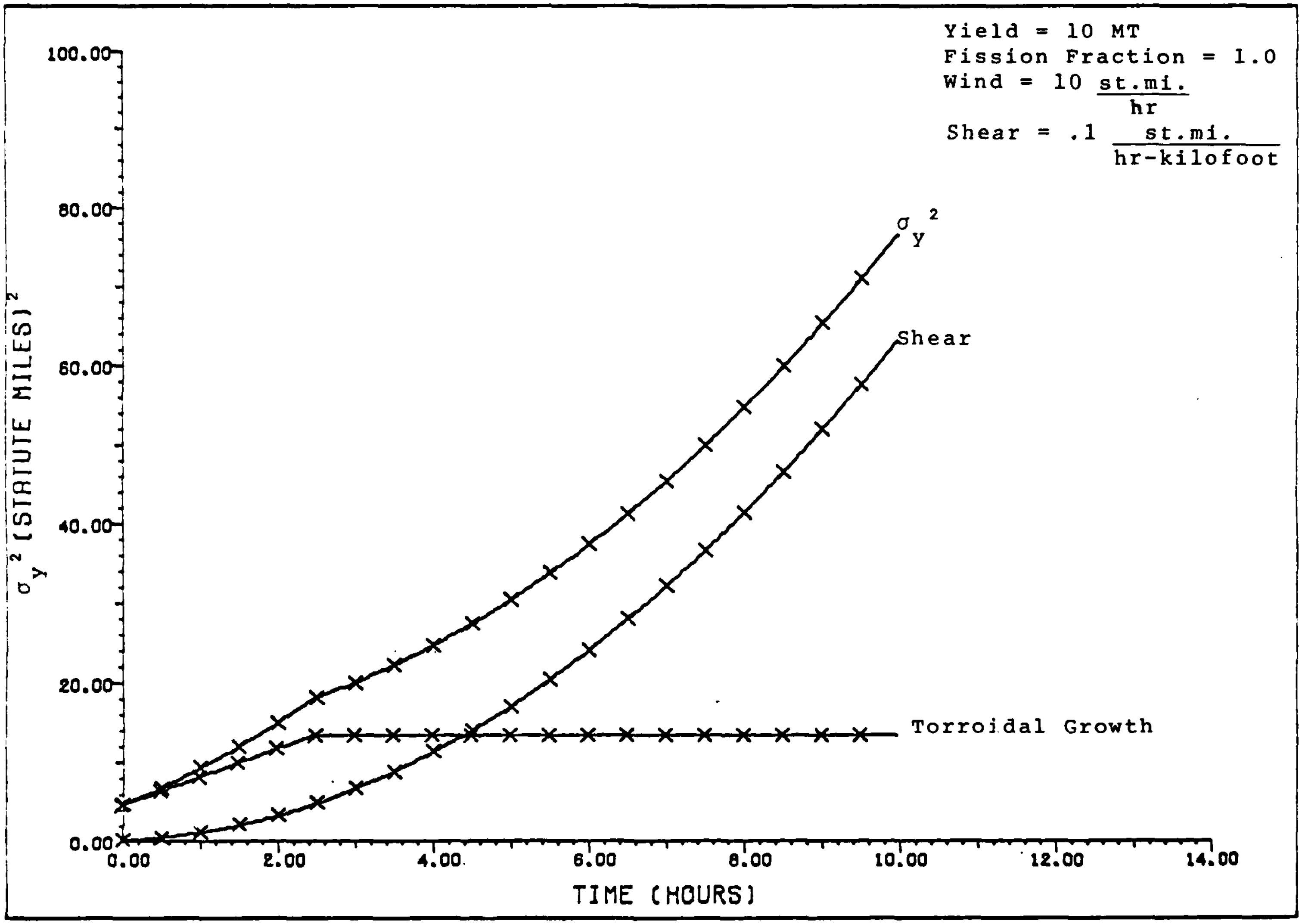

Figure 6. σ_y^2 vs. Time

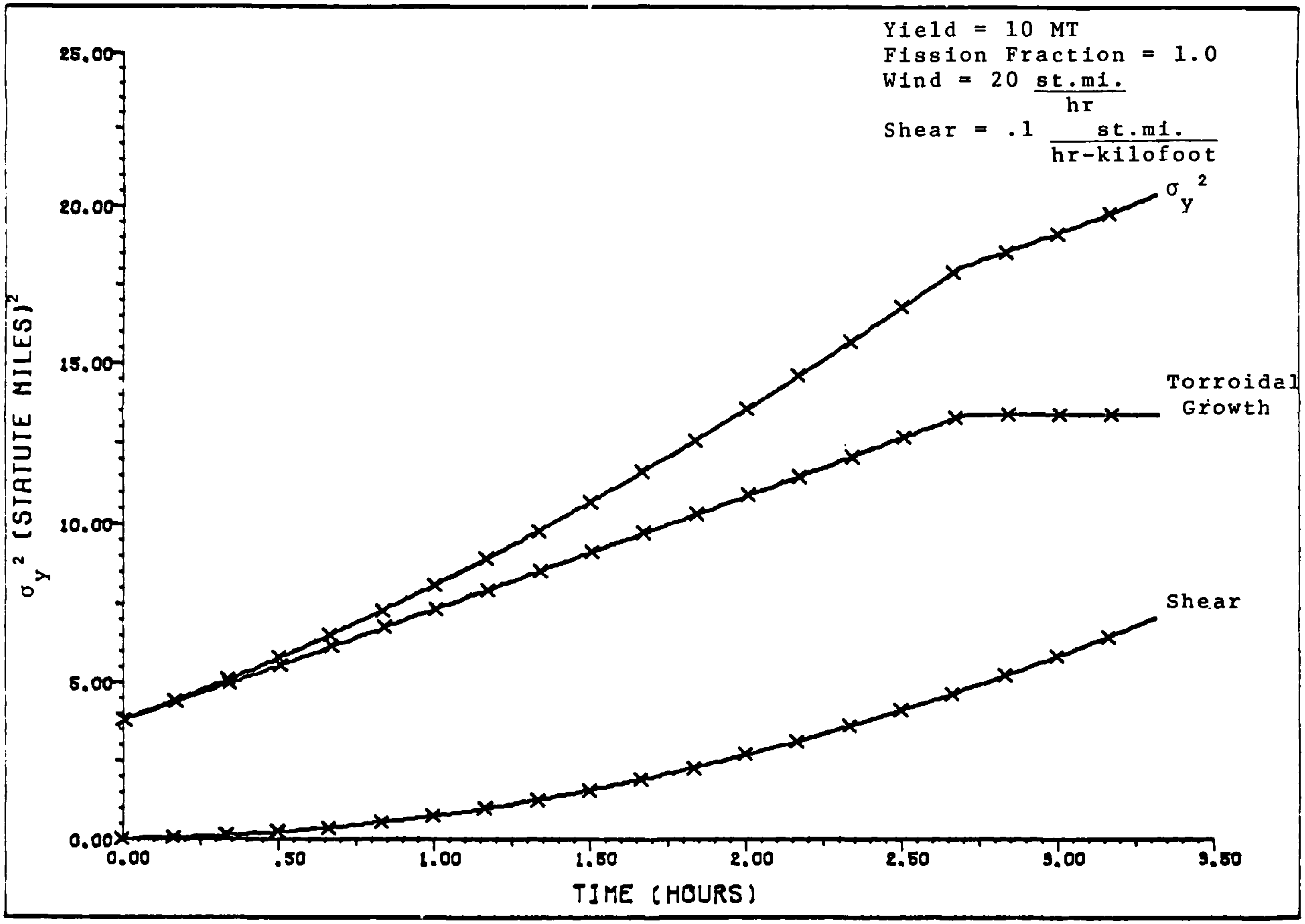

Figure 7. σ_y^2 vs. Time

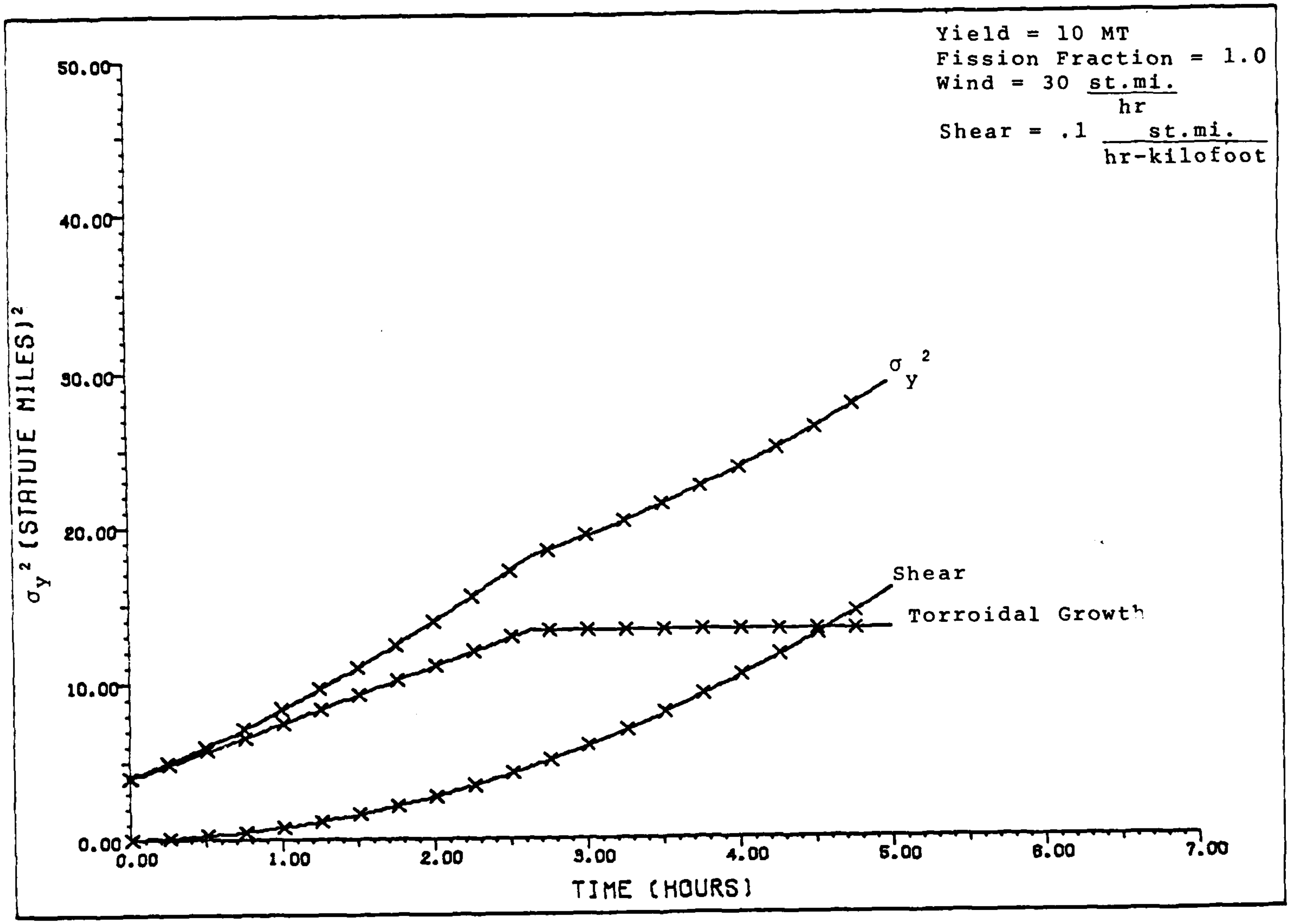

Figure 8. σ_y^2 vs. Time

were generated using the subroutine Dose with an appropriate main program designed for plotting with the Calcomp plotter in Building 640. Additional graphs are available for several wind and shear combinations in Appendix C.

<u>Torroidal Growth</u>

As seen from Figures 6-8, the torroidal growth term predominates at early time. It is defined in Equation (9) as $\sigma_o{}^2(1 + \frac{8}{L}|x + 2\sigma_x|)$. In the absence of shear, WSEG assumes this expression relates the compressed dimensions of the fallout pattern near ground zero to the fallout cloud dimensions as a function of time. WSEG defines the radius of the fallout pattern as σ_e, the "effective radius" where the effective radius is arbitraily assumed equal to one-half the radius of the stabilized fallout cloud at 15 minutes and where $\sigma_e{}^2 = \sigma_o{}^2(1 + \frac{8}{L}|x + 2\sigma_x|)$.

Initially Pugh and Galiano defined $\sigma_e{}^2$ as $\sigma_o{}^2(1 + \frac{x}{\text{Wind}})$ without derivation or reference where $\frac{x}{\text{Wind}}$ represents time after burst in hours (Ref. 1:13). It is this form which resembles simple diffusion according to Fick's Law. There are, however, several serious inconsistencies with this assertion which are evident in the following discussion which develops both the present form of $\sigma_e{}^2$ used in Equation (9) and the diffusivity parameter (D_V) for Fick's Diffusive Law (see Appendix D).

First, while the expression for $\sigma_e{}^2$ resembles diffusive growth, it was originally intended to allow for torroidal

growth (Ref. 9). In either case, without modification, the initial expression for σ_e^2 is dimensionally incorrect!

Pugh and Galiano corrected this problem by substituting the ratio L/T_c for Wind where L_o is defined as Wind . T_c and $L \approx L_o$ when $L_o^2 >> 2\sigma_o^2$ (see Equations (7) and (10)). At this point, Pugh and Galiano assigned T_c a dimensionless value of 8 which corrected the units problem and compensated for various yields greater than 1 megaton. There is no apparent reason for deleting the units except convenience.

Two further modifications were made to σ_e^2 resulting in its present form. The first modification set $x = |x|$ to account for both downwind and upwind fallout pattern growth. The second modification set $|x| = |x + 2\sigma_x|$ which prevented a minimum σ_e at ground zero.

To derive an expression for Diffusivity (D_v) according to Fick's Law, σ_e^2 is first defined as $\sigma_o^2(1 + \frac{8|x|}{L})$ which is a good assumption if $X >> 2\sigma_x$. Wind . T_c is substituted for L by the same reasoning used earlier to develop this expression and the result is $\sigma_e^2 = \frac{8}{T_c} \cdot \frac{x}{\text{Wind}} \cdot \sigma_o^2 + \sigma_o^2 = \sigma_o^2 + \frac{8}{T_c}\sigma_o^2 t$. T_c and σ_o are allowed to vary according to yield, t is time in hours after burst. Diffusivity according to Fick's Law is therefore:

$$D_{WSEG} = D_v = \frac{4}{T_c}\sigma_o^2 \quad \left(\frac{(\text{st.mi.})^2}{\text{hours}}\right) \quad \text{(See Appendix D)} \qquad (30)$$

Assuming D_{WSEG} is dimensionally correct, a comparison of the Diffusivity parameter and diffusive growth was made between WSEG and the Department of Defense Land Fallout Prediction System (DELFIC). The following data was supplied by Major Scott Bigelow, Air Force Weapons Lab (AFWL) using DELFIC for a single particle size group:

Yield = .1 megatons

H_c = 9.0 kilometers

σ_o = 2607 meters

σ_f = 2863 meters

t_o = 611 sec

t_f = 2.6 x 10^4 sec

Radius of particle group = 33.8 microns

Diffusivity was calculated from the above data using DELFIC as:

$$D_v = 5 \times 10^{-6} \frac{\text{meters}^2}{\text{sec}}$$

where the quantity $(\sigma_f - \sigma_o)$ represents cloud growth due to the diffusive process in time $(t_f - t_o)$.

For .1 MT burst using WSEG: Mean radius of particle for WSEG activity/size distribution = 44 microns.

T_c = 4.995 hours

H_c = 9.1 kilometers (Equation (1))

$$D_{WSEG} = \frac{4(\sigma_o)}{4.995} \frac{(\text{st.mi.})^2}{\text{hr}}$$

and σ_o = .736 statute miles (from Equation (3))

Therefore

$$D_{WSEG} = \frac{4(.736\ \text{st.mi.})^2}{(4.995)(3600\ \frac{\text{sec}}{\text{hr}})} = \frac{4(1182.86\ \text{meters})^2}{(4.995)(3600\ \frac{\text{sec}}{\text{hr}})}$$

$$D_{WSEG} = 310.96\ \frac{\text{meters}^2}{\text{sec}}$$

Clearly the magnitude of "diffusivity" represented in WSEG is something entirely different than the slow diffusive process represented by the DELFIC D_v. Further, assuming the fallout cloud radius in DELFIC can be represented as $2\sigma_e$ (as in WSEG), the radius shows a diffusive growth of 512 meters in 7.0525 hours. Using the identical time, the WSEG cloud radius would show a growth of 1.58×10^7 meters. Applying the cutoff of three hours, the growth is still 7.72×10^6 meters!

Therefore, while the form, excluding dimensionality, appears to fortuitously resemble diffusive growth, it does not provide proper parameters as diffusion is a small part of cloud growth. Also the model places a three hour time limit on the effects of this term which corresponds to a contribution to σ_y^2 of 13.334 (st.mi.)^2. This also is not reasonable for diffusive growth as it would continue until fallout deposition is completed.

IV. Conservation

The purpose of this section is to examine the capability of WSEG to deposit within the fallout pattern all activity assumed initially present in the fallout cloud at t = 15 minutes. This total activity is a product of yield, Source Normalization Constant (SNC), and fission fraction which is taken in WSEG as 2×10^6 (yield)(fission fraction) $\frac{\text{Roentgens(st.mi.)}^2}{\text{hr}}$.

In order to recover this product, D_{H+1} was integrated over the entire fallout pattern. Crosswind integration was accomplished analytically while the downwind/upwind integration was accomplished numerically using a trapezoidal technique. Also included is a discussion of the effect on conservation of activity in WSEG by substituting $\int_b^a \phi . g(x)dx$ for $\int_o^a g(x)dx$ within Equation (21) where a and b represent finite integration limits used to make the trapezoidal integration possible.

This examination specifically focuses on the crosswind transport function, f_y, defined by Equation (22) and its effect on conservation as yield and Wind are varied. The function f_y is not properly normalized due to the addition of α_2. In order to evaluate the effect of f_y on conservation and eliminate uncertainty in the results due to the numerical integration technique used, the recovered product was compared to results obtained under identical conditions in an identical manner using the crosswind transport function

originally defined by Pugh and Galiano without α_2. This original transport function is defined as:

$$f_y = \frac{\exp-\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2}{\sqrt{2\pi}\sigma_y} \text{ (Ref. 1:10)} \tag{31}$$

For the purposes of this section the original transport function will be distinguished from Equation (19) by referring to it as f_{yo}.

The following subsections discuss the specific method by which conservation was examined and the results of this examination. These results are tabulated in Tables I through III in this section. All calculations were done using the ASD CYBER 74 computer using subroutine Dose.

Method/Results

The total activity within the fallout ground pattern is:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_x f_y \, dxdy = \text{SNC. fission fraction . Yield} \tag{32}$$

where f_x and f_y are defined by Equations (21) and (22) and fission fraction = 1.0. The product $f_x \cdot f_y$ at any x and y defines D_{H+1} at that location. The upwind/downwind integration limits were replaced by finite values, a and b, which are defined on page 34.

To reduce the numerical integration in Equation (32) from two dimensions to one, the crosswind integration was first accomplished analytically from $-\infty$ to $+\infty$ using the properties of a standard Gaussian distribution. In this case however,

$_{-\infty}\int^{\infty} f_y dy \neq 1$ since f_y is not properly normalized because of α_2. Recall from Equation (23) that α_2 is a function of yield, wind and downwind/upwind distance. This dependence on x is not subscripted.

It can be shown at any x:

$$f_y = \frac{\alpha_2}{\alpha_2} \cdot f_y = \frac{\alpha_2 \ \exp-\frac{1}{2}\left(\frac{y}{\alpha_2 \sigma_y}\right)}{\sqrt{2\pi}\sigma_y \alpha_2}$$

where
$$\frac{\exp-\frac{1}{2}\left(\frac{y}{\alpha_2 \sigma_y}\right)}{\sqrt{2\pi}\sigma_y \alpha_2}$$

is a standard normalized Gaussian distribution which if integrated from $-\infty$ to $+\infty$ would equal 1. Therefore at any x:

$$_{-\infty}\int^{\infty} f_y dy = \alpha_2 \ _{-\infty}\int^{\infty} \frac{\exp-\frac{1}{2}\left(\frac{y}{\alpha_2 \sigma_y}\right)^2}{\sqrt{2\pi}\sigma_y \alpha_2} dy = 1 \ . \ \alpha_2$$

If y = 0,a simple substitute for the crosswind integration is available because $f_y(0) = \frac{1}{\sqrt{2\pi}\sigma_y}$ and therefore $\alpha_2 f_y(0)\sqrt{2\pi}\sigma_y = 1 \ . \ \alpha_2$. Placing the relationship in Equation (27) reduces it to the following:

$$_b\int^a \alpha_2 f_y(0) \ \sigma_y \sqrt{2\pi} f_x dx = \text{SNC} \ . \ \text{Yield} \tag{33}$$

where $f_y(0) \ . \ f_x = D_{H+1}$ along the hotline. This hotline is an imaginary line extending directly downwind or upwind of ground zero where maximum activity is deposited. (See x axis in Figure 1). The function σ_y and α_2 are defined by

Equations (9) and (23) respectively and a and b define the finite integration limits explained in the next paragraph. The shear contribution to σ_y was neglected throughout this section as it was found to have no effect on conservation.

The remaining upwind and downwind integration was accomplished simply by a trapezoidal integration of D_{H+1} along the hotline beginning at ground zero. Criteria for the integration limits was based upon dose rate contours. Trial and error determined the limiting contour that maximized the recovered activity in a zero Wind condition where α_2 is ineffective while minimizing computer time. Activity lost was less than .1% in the cases examined when the .1 Roentgen/hour dose rate contour was used. Maximum upwind (a) and downwind (b) distance traveled to the .1 Roentgens/hr dose rate contour were used as integration limits and noted for comparison. These limits vary with yield and wind. As a second check, $\phi.g(x)$ was also trapezoidally integrated between a and b to be sure that all activity available for deposition was deposited. Step size for g(x) and dose rate integration was identical for each wind and yield condition. These step size varied from .0001 to .1 statute miles depending on the conditions. The results are tabulated in Table I.

It can be seen that the present WSEG model is not conservative by some average effective α_2 where this average α_2 is the ratio of the recovered activity to the initial activity. Table I indicates a significant reduction in recovered product (SNC . Yield) at low yields and high Wind

TABLE I

Comparison of Initial vs. Recovered SNC . Yield
For the Present Version of WSEG

Yield	Wind $\frac{\text{st.mi.}}{\text{hr}}$	Initial SNC . Yield $\frac{\text{R-(st.mi.)*}}{\text{hr}}$	Recovered SNC . Yield $\frac{\text{R-(st.mi.)*}}{\text{hr}}$	Cumulative g(x) (per st.mi.)
1KT	0	2×10^3	2.000×10^3	1.0000
	30		1.590×10^3	0.9991
	60		1.370×10^3	0.9983
10KT	0	2×10^4	2.000×10^4	1.0000
	30		1.782×10^4	0.9997
	60		1.678×10^4	0.9994
100KT	0	2×10^5	2.000×10^5	1.0000
	30		1.931×10^5	1.0000
	60		1.889×10^5	1.0000
1MT	0	2×10^6	2.000×10^6	1.0000
	30		1.970×10^6	1.0000
	60		1.948×10^6	1.0000
10MT	0	2×10^7	2.000×10^7	1.0000
	30		1.985×10^7	1.0000
	60		1.973×10^7	1.0000
100MT	0	2×10^8	2.000×10^8	1.0000
	30		1.992×10^8	1.0000
	60		1.986×10^8	1.0000

*"R" is an abbreviation for Roentgens.

since $\alpha_2 \neq 1$. When the Wind = 0, the recovered activity at all yields is identical to the activity recovered using f_{yo} (defined by Equation (31)) in a zero Wind condition. In this condition $\alpha_2 = 1.0$ and has no effect thereby normalizing the crossrange distribution function. The lower yields are more dramatically affected since much more activity is deposited in a short time period. Recall α_2 is effective for 2 hours after stabilization. The net result is to reduce the total activity deposited within the .1 $\frac{\text{Roentgens}}{\text{hr}}$ dose rate contour by the percentages shown in Table II. Cumulative $\phi . g(x)$ is very close to 1.0 in all cases indicating that all activity has been deposited.

The case of the original distribution, f_{yo} defined by Equation (31), was handled in the same manner as described earlier where:

$$\int_{-\infty}^{\infty} f_{yo}(0)\,dy = 1$$

Again, a simple substitute is available to reduce the necessary integration to one dimension through the properties of a Gaussian distribution. If y = 0 then $f_{yo}(0) = \frac{1}{\sqrt{2\pi}\sigma}$. Thus $\sigma_y\sqrt{2\pi}\ f_{yo}(0) = 1$ and this expression is substituted into Equation (32) which simplifies to:

$$\int_b^a f_y(0)\ \sigma_y\sqrt{2\pi}\ f_x\,dx = \text{SNC} \ .\ \text{Yield} \tag{34}$$

where $f_y(0)\ .\ \sigma_x = D_{H+1}$ along the hotline and σ_y is defined by Equation (9). The integration limits are a and b.

TABLE II

Per Cent Decrease of Recovered Activity vs. Yield and Wind

Yield	Wind (st.mi.)/hr	Per Cent Decrease
1KT	0	0.0
	30	20.6
	60	31.5
10KT	0	0.0
	30	10.9
	60	16.1
100KT	0	0.0
	30	3.4
	60	5.6
1MT	0	0.0
	30	1.5
	60	2.6
10MT	0	0.0
	30	0.8
	60	1.4
100MT	0	0.0
	30	0.4
	60	0.7

Again, upwind and downwind integration was accomplished by trapezoidally integrating D_{H+1} along the hotline beginning at ground zero. Integration limits and step sizes were identical to those used for the present distribution for each wind and yield condition. $\phi.g(x)$ was integrated trapezoidally as before.

The eighteen cases examined for the yield and wind conditions specified in Table I conserved activity to three or four significant figures. A slight reduction in recovered activity was noted at high winds for each yield accompanying a reduction in cumulative $\phi.g(x)$. This is due to the finite nature of the downwind/upwind integration limits signifying that small amounts of activity still remained suspended in the cloud at the completion of the integration.

To complete this examination of conservation, it was also necessary to verify that ${}_b\int^a \phi.g(x)dx = {}_0\int^a g(x)dx$ in Equation (18) for the yield and wind conditions used in this section. To do so required setting $\phi = 1.0$ and integrating Equation (32) as before. The function f_y was integrated analytically from $-\infty$ to $+\infty$ in the manner described above. The remaining downwind integration was again accomplished numerically using the trapezoidal technique described earlier in this section. This time however, the integration limits were from ground zero ($x = 0$) to the .1 Roentgens/hr dose rate contour. The function $g(x)$ was separately integrated via trapezoidal integration. Downwind distance (a)

TABLE III

Comparison of Distance Traveled Downwind (a) While Integrating the Fallout Pattern to Recover SNC . Yield for the Present Version of f_y

Yield	Wind (st.mi.)	(a) with g(x) (Nautical Miles)	(a) with ϕ.g(x) (Nautical Miles)
1KT	0	0.988	0.957
	30	120.6	120.6
	60	217.5	217.5
10KT	0	01.92	01.87
	30	485.6	485.6
	60	888.2	888.2
100KT	0	06.90	06.62
	30	1256.	1256.
	60	2330.	2330.
1MT	0	17.63	17.23
	30	2254.	2254.
	60	4237.	4237.
10MT	0	41.66	40.79
	30	3256.	3256.
	60	6180.	6180.
100MT	0	95.56	93.75
	30	4240.	4240.
	60	8104.	8104.

to the .1 Roentegens/hr dose rate contour for each Wind and yield condition was compared with the downwind distance used to generate the data in Table I. The step sizes used during this numerical integration were identical to those used earlier for each yield and Wind condition.

In the eighteen cases examined (specified by Table 1) the recovered activity and cumulative g(x) were identical to the data presented in Table 1 to four significant figures. Also as Table III indicates, the downwind limit used is identical for both cases to four significant figures for winds greater than 0. For a zero Wind condition, the disparity fluctuates between 3.1% at 1 KT in "x" to 1.9% at 100 MT. This is not significant when one considers the integration technique and the relationship of g(x) and ϕ.g(x) as in Figure (3). Thus, the use of $_{b}\int^{a}\phi.g(x)dx$ or $_{0}\int^{a}g(x)dx$ in Equation (18) does not affect model conservation.

Conclusion

WSEG, as presented by Pugh and Galiano in their original work is mathematically conservative. It, however, from modifications in 1962, did not reflect an accurate picture of the true fallout pattern based upon later data. The 1962 version represents this data more adequately but as demonstrated in this section, is not conservative because of the addition of α_2 to f_y. The effect is seen primarily at yields less than 1.0 MT with high winds.

V. Computer Implementation

The Fortran subroutine containing the WSEG model located in Appendix A was adapted to the ASD CYBER 74 computer and coupled with a main program designed to generate output identical to the sample output also contained in Appendix A on pages 58-61. All work was subsequently done on the ASD CYBER 74 computer and specific user instructions concerning program operation are contained in Appendix E. Additionally this program is designed to output g(t), ϕ.g(t), g(x), cumulative ϕ.g(x), the g(t) time constant, and the g(t) exponent (n).

The results are contained in Appendix B, pages 72-75 for four conditions used to validate the computer program. In all cases the yield used is .01 MT and the shear is .1 knots/kilofeet. The effective wind varies from one to ten knots and the fission fraction is assumed 1.0. As seen, the output generated for this thesis is nearly identical to the output in Appendix A for each wind condition. Downwind and crosswind range deviations are limited to .1 nautical miles or less and dose rate deviations are less than 10 Roentgens/hr.

As a final note, the output created during this independent study and presented in Appendix B is not exactly identical with the sample output of Appendix A for two reasons: One, the subprograms programs providing the cumulative normal and the gamma functions were locally created and may not

provide the same accuracy as those used to generate the sample output in Appendix A; two, the step size used to generate the sample output was unknown. This factor plays a critical role when attempting to duplicate earlier work.

VI. WSEG Limitations

The purpose of this section is to discuss several limitations of the WSEG model that have been discovered either by researching literature or through experience using the model. Some of the following limitations have been mentioned earlier in this report:

1. The model cannot account for complex wind or shear patterns. This restriction leads to poor results. Whether results are high or low depends on the test data evaluated and the accuracy of the wind data.
2. The model is unable to account for meteorological conditions such as rain, snow, etc.
3. Stabilized cloud parameters appear to be inaccurately predicted when compared with other models (Refs. 7:84; and 5:17). The net result is a reduced fallout pattern area as both downwind and crosswind displacement are affected. WSEG also underpredicts σ_y and cloud center heights at low and high yields. This inaccuracy is partially compensated for because σ_o is overpredicted.
4. WSEG produces peak concentrations, for the condition of Wind $\neq 0$, that occur at very nearly the same downwind location regardless of wind velocity. To explain this error, recall that

the downwind distribution function is $\phi \cdot g(x)$. The parameter "α_1" defined by Equation (22) within ϕ varies according to effective wind velocity. Higher wind velocities lower the magnitude of α_1 thereby driving ϕ to a maximum or minimum more rapidly as one marches downwind or upwind respectively from ground zero. Also a time limit for the argument of ϕ was established through subroutine logic which if exceeded set $\phi = 1$.

Figure (9) depicts this discrepancy clearly. It represents D_{H+1}/Yield versus distance for several wind conditions where D_{H+1} is the hot-line value. Winds are in units of $\frac{\text{st.mi.}}{\text{hr}}$. The yield condition used was chosen for convenience during preliminary work. Note the peaks, when affected by effective wind, occur at very nearly the same downwind location. In fact, the peak for the 60 $\frac{\text{st.mi.}}{\text{hr}}$ curve even appears closer to ground zero than that of the 40 $\frac{\text{st.mi.}}{\text{hr}}$ curve.

This error indicates that either the effective wind velocity affects the fall rates or that the peaks are caused by large particles whose downwind position is independent of wind. In both cases the inconsistencies are obvious. In the first case the effective wind is a horizontal contribution to the translation of

activity and has no effect vertically. The second case does not account for the transition from the "0" wind condition with a peak at ground zero to a variety of wind conditions resulting in peaks at almost the same downwind location.

5. The "0" wind curve in Figure (9) has an obvious asymmetry. The explanation involves the torroidal growth expression in σ_y which is defined as $\sigma_o(1 + \frac{8|x + 2\sigma_x|}{L})$. This term dominates in a "0" shear environment. The inclusion of $2\sigma_x$ within the absolute value sign resulted in a reduction in the magnitude of σ_y for upwind calculations when compared to downwind calculation at the same $|x|$. The reason is that σ_x is always positive. This effect coupled with the three hour effectiveness of torroidal growth produced the asymmetry. A correction is made simply by defining the torroidal growth expression as $\sigma_o\ (1 + \frac{8\ (|x|\ +\ 2\sigma_x)}{L})$. This correction is used in Figure (10). Note that the curves with 10, 20, 40, 60 $\frac{\text{st.mi.}}{\text{hr}}$ winds in Figures (9) and (10) are identical. This discrepancy had no effect in downwind fallout pattern computation for an environment with wind.

6. The use of the Source Normalization Constant (SNC) at $2 \times 10^6\ \frac{\text{Roentgens-mi}^2}{\text{hr MT}}$ adjusts total

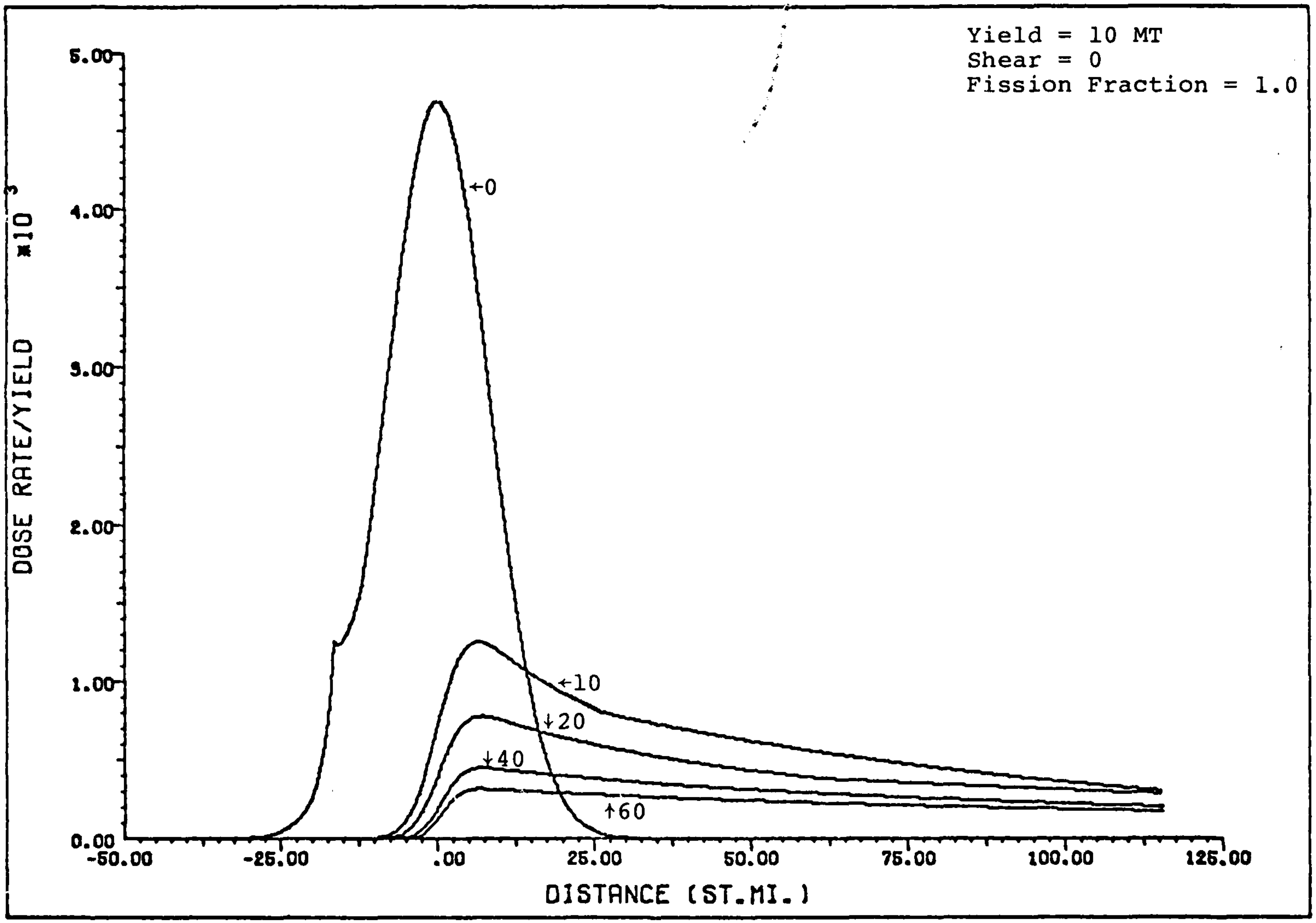

Figure 9. Hotline D_{H+1}/Yield vs. Distance

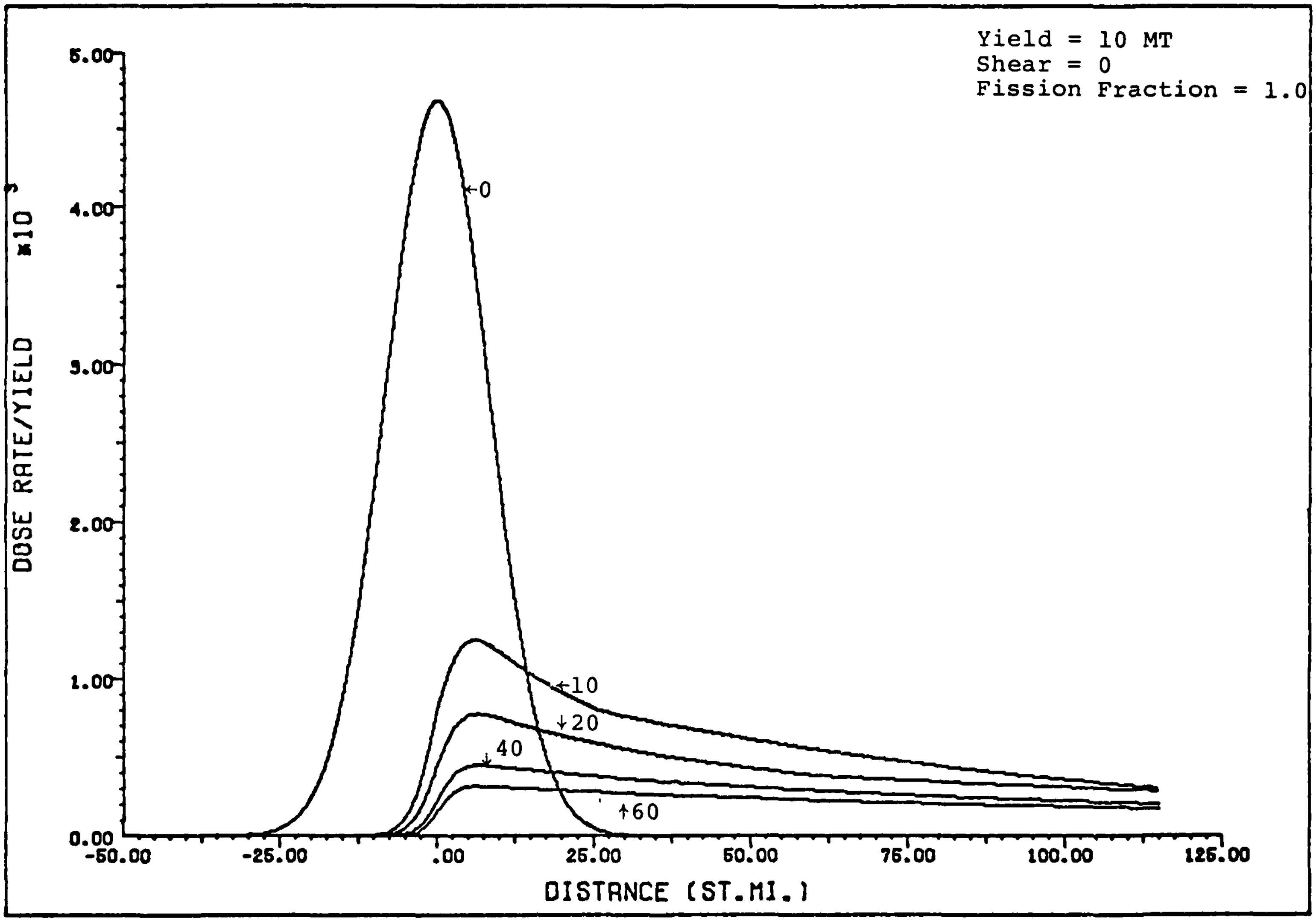

Figure 10. Modified Hotline D_{H+1}/Yield vs. Distance

activity deposited as local fallout at 80% of fallout entering the cloud regardless of yield.

7. The choice of Source Normalization Constant used by WSEG is three to four times greater than used by later models (Ref. 7:85). This, if the other models are accurate, would cause an overprediction.

8. The model generates contour patterns that are nearly elliptical in shape. As seen, the computer code in Appendix B solves for crosswind component (y) using a Gaussian distribution. Complex patterns are therefore not possible.

VII. Summary

The purpose of this thesis is to recreate and document, for local use, the most popular analytical fallout model, WSEG-10. Additionally several sections were also devoted to analyzing different facets of WSEG-10. This study will provide a basis for future fallout studies.

The first section discussed the WSEG-10 model from the original document by Pugh and Galiano (see Ref. 1) including later revisions. An explanation of terms was provided where possible.

The second section contained an analysis of the cross-range dispersion term, σ_y. It was found that shear effects predominate at late times after burst while the torroidal growth term is dominant soon after burst. Graphs of several wind and shear conditions can be seen in Figures (6), (7), or (8) and in Appendix C.

Also discussed was the resemblance of the torroidal growth term to a term representing diffusive growth based on Fick's Law. Appendix D contains a development of Diffusivity from Fick's Law for comparison. The results indicated that the process defined by Pugh and Galiano was not diffusive growth for the following reasons:

1. Arbitrary deletion of units in the torroidal growth term. T_c was assigned a dimensionless value of 8. This produced the resulting units for Diffusity.

2. When compared with diffusive growth modeled by DELFIC, the WSEG expression for torroidal growth was many orders of magnitude greater.

3. A three hour limit was placed on the effects of this term thereby restricting its contribution.

The third section discusses the property of conservation for the WSEG model. Results demonstrated that activity was conserved regardless of the upwind/downwind normalized distribution function choosen within the context of that section. Only with the original crossrange distribution, f_{yo}, however, did WSEG conserve activity. The 1962 version, which is also the present version of f_y, is unnormalized resulting in significant losses at low yields and high winds. It was also found that varying shear conditions did not affect conservation.

The fourth section describes computer implementation of the subroutine Dose obtained from Mr. Ralph Mason. Subroutine Dose contains the analytical expressions developed in the WSEG model consolidated in subroutine form for easy use. Output nearly identical to that provided in Appendix A is contained in Appendix B. Appendix B also contains a computer listing of the AFIT version of WSEG along with a definition of terms and sample results. A program user's guide is in Appendix E.

The last section discusses a series of weaknesses or limitations to the model discovered either through computer use or researching the literature for this thesis. Inconsistencies covered in discussions concerning σ_y or conservation were not included in this section. Several of these weaknesses

included a D_{H+1} asymmetry in a "0" wind condition and peak D_{H+1} at nearly the same downwind location for winds between 10 and 60 $\frac{\text{st.mi.}}{\text{hr}}$.

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Appendix A

Subroutine Dose and Sample Output

This appendix contains the Fortran subroutine Dose obtained from Mr. Mason, National Military Command Support Center. Also included is a series of sample results for the following conditions:

Yield = .01/.03 MT

Shear = .1 knots/kilofeet

Fission Fraction = 1.0

Wind - 1.0 to 10.0 KTS

No modification has been done to the subroutine. References to "dose" in the sample output actually refer to dose rate in Roentgens/hr.

```
      SUBROUTINE DOSE(DB,DH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,
      YIELD)
C     THIS SUBROUTINE IS THE FEBRUARY 23, 1962 VERSION WITH
C     ALL CHANGES + MODIFICATIONS TO RESEARCH MEMORANDUM 10
C     INCORPORATED.  USERS WILL BE INFORMED OF ANY LATER
C     MODIFICATIONS.
C     IN NORMAL FULL CALLS,
C     OUTPUT PARAMETERS
C          DB=THE BIOLOGICAL DOSE IN ROENTGENS (INFINITE
C            PLANE DOSE)
C          DH=THE H+1 DOSE RATE IN ROENTGENS (INFINITE PLANE
C            DOSE)
C          SIGYA2=THE TERM SIGMA Y SQUARED IN SQUARE NAUTICAL
C            MILES
C           (SOMETIMES USEFUL IN INTEGRATION OF DOSE AREAS)
C     INPUT PARAMETERS
C          YY=THE CROSSWIND DISTANCE PERPENDICULAR TO THE
C            WIND DIRECTION IN NAUTICAL MILES
C          XX=THE DISTANCE ALONG THE X AXIS PARALLEL TO THE
C            WIND DIRECTION IN NAUTICAL MILES.  (XX IS NEG-
C            ATIVE FOR UPWIND LOCATIONS)
C          SHEAR=THE CROSSWIND COMPONENT OF SHEAR
C          WIND=THE EFFECTIVE FALLOUT WIND IN KNOTS
C          FFRAC=THE FISSION FRACTION
C          YIELD=THE YIELD IN MEGATONS
C     NOTE THAT CALCULATIONS ARE NOT REPEATED FOR PARAMETERS
C     THAT HAVE NOT CHANGED.  THEREFORE, THE CALL MAY BE
C     SHORTENED TO EXCLUDE THOSE PARAMETERS AT THE END OF
C     THE CALLING SEQUENCE THAT REMAIN THE SAME.
C          CALL DOSE(DB,DH,SIGAY2,YY)
C     THIS SUBROUTINE MAY BE USED AS A FUNCTION SUBROUTINE
C     WITH THE VALUE OF THE FUNCTION EQUAL TO THE BIOLOGICAL
C     DOSE.
C          ANSWER=DOSE(DB,DH,SIGAY2,YY,XX,SHEAR,WIND,FFRAC,
C            YIELD)
C     IS EFFECTIVELY    ANSWER=DB
C     A THIRD USE IS TO INPUT XX AND THE DOSE AND RECEIVE
C     AS OUTPUT THE CORRESPONDING YY IN NAUTICAL MILES.
C     (USEFUL IN COMPUTATION OF FALLOUT CONTOURS)
C          CALL DOSE(YDH,YDB,-DOSE,YY,XX,SHEAR,WIND,FFRAC,
C            YIELD)
C          YDH=THE YY DISTANCE IN NAUTICAL MILES FOR AN H+1
C            INPUT DOSE
C          YDB=THE YY DISTANCE IN NAUTICAL MILES FOR A BIO-
C            LOGICAL DOSE
C          -DOSE=MINUS THE VALUE OF THE DOSE
C          ALL OTHER PARAMETERS ARE THE SAME AS ABOVE
```

```
      IF(YIELD-OLDYLD)      1,2,1
C     YIELD DEPENDENT CALCULATIONS
  1   OLDYLD=YIELD
      YMT=LOGF(YIELD)
      T3=2000000.*YIELD
      SIGO=.7+YMT/3.-3.25/(4.*(YMT+5.4)**2)
      SIGO=EXPF(SIGO)
      SIGO2=SIGO*SIGO
      T1=YMT+2.42
      H=44.+6.1*YMT=.205*T1*ABSF(T1)
      SIGH-.18*H
      SIGN2=SIGH*SIGH
      T2=H/60
      T=(12.*T2-2.5*T2*T2)*(1.-.5*EXPF(-(H/25.)**2))*
        1.0573203
      GO TO 3
  2   IF(WIND-OLDWIND)      3,5,3
C     WIND DEPENDENT CALCULATIONS
  3   OLDWIND=WIND
  4   ZL0=WIND*T*1.151515
      ZLO2=ZLO*ZLO
      SIGX2=SIGO2*(ZLO2+8.*SIGO2)/(ZLO2+2.*SIGO2)
      SIGX=SQRTE(SIGX2)
      ZL2=ZLO2+2.*SIGX2
      ZL=SQRTE(ZL2)
      T14=ZLO2+.5*SIGX2
 40   ZN=(ZLO2+SIGX2)/T14
      IF(ZN-1.002)      102,102,103
102   ZN=1.
      T20=1.
      GO TO 42
103   T20=GAMMA(1.+1./ZN)
 42   T4=T3/(ZL*T20*2.5063)
      PALPH=.001*H*WIND*1.151515/SIGO
      ALPH1=1./(1.+PALPH)
      T5=ZLO/(ZL*ALPH1*SIGX)
      T6=2.*SIGX2*T*T*SIGN2/ZL2
      T15=ZLO2/ZL2
      T7=T15*T*T*SIGH2
      GO TO 6
  5   IF(SHEARY-OLDSHR)      6,8,6
C     SHEAR DEPENDENT CALCULATIONS
  6   OLDSHR=SHEARY
  7   T21=SHEARY*SHEARY*1.325975
      T8=T6*T21
      T9=T7*T21/ZL2
      GO TO 9
  8   IF(XX-OLDX)      9,116,9
C     X DEPENDENT CALCULATIONS
  9   OLDX=XX
      X=XX+6080./5280.
 10   T10=X+2.*SIGX
      T11=1.+(8.*ABSF(T10))/ZL
```

```
      IF(T11-4.)      12,12,11
 11   T11=4
 12   T22=T11*SIGO2
      T30=T5*X
      IF(T30-6.)      35,36,36
 36   T30=1.
      GO TO 37
 35   T30=CUMNOR(T30)
 37   T12=T9*T10*T10
 43   IF(X)     13,14,13
 14   T13=1.
      TO TO 15
 13   IF(ZN-1.)     113,114,113
114   T13=EXPF(-(ABSF(X)/ZL))
      TO TO 15
113   T13-EXPF(-(ABSF(X)/ZL)**ZN)
 15   SIGY2=T22+T8+T12
      SIGY=SQRTE(SIGY2)
      TARR=SQRTE(.25+(T15*T10*T10*T*T*2.*SIGX2)/T14)
      BETA=LOGE(TARR/31.6)
      ZLD=-.287-.52*BETA-.04475*BETA*BETA
      BIO=EXPE(ZLD)
      IF(WIND)     27,27,53
 53   T23=(2.*X)/(WIND*1.151515)
      IF(T23-10.)     28,28,27
 27   ALPH22=1.
      GO TO 29
 28   T24=CUMNOR(T23)
      ALPH22=1./(1.+PALPH*(1.-T24))
 29   ALPH2=ALPH22*ALPH22
      IF(SIGYA2)     91,90,90
      TO CALCULATE V, GIVEN X AND A DOSE
 90   SIGYA2=SIGY2*ALPH2
      GO TO 17
 91   DHX0=T30*T13*T4*FFRAC/SIGY
      DBXO=DHXO*BIO
      DOSEL=ABSF(SIGYA2)
      IF(DOSEL)     95,117,95
 95   IF(DHXO/DOSEL-1.)     94,94,92
 94   DH=0.
      GO TO 93
117   DH=0.
      DB=0.
      RETURN
 92   DH=ALPH22*SIGY*SQRTE(2.*LOGE(DHXO/DOSEL))*5280./6080.
 93   DB=ALPH22*SIGY*SQRTE(2.*LOGE(DBXO/DOSEL))*4380./6080.
      RETURN
116   IF(SIGYA2)     91,16,16
 16   IF(YY-OLDY)     17,19,17
C     Y DEPENDENT CALCULATIONS
 17   OLDY=YY
      Y=YY*6080./5280.
 18   T16=EXPE(-.5*Y*Y/(ALPH2*SIGY2))/SIGY
```

```
      GO TO 22
19    IF(FFRAC-OLDFRAC)       20,22,20
20    OLDFRAC=FFRAC
21    DH=DDH*FFRAC
      DB=DDB*FFRAC
      RETURN
22    DDH=T30*T16*T13*T4
      DDB=DDH*BIO
      GO TO 20
      END
      END
```

100% Fission

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 1.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.6	10.2	4.2	6.4
30.	-0.5	8.2	3.1	5.1
100.	-0.5	6.0	2.2	3.6
300.	-0.4	4.2	1.4	2.4
1000.	-0.3	2.5	0.8	1.1
3000.	-0.1	1.1	0.4	0.4
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 5538. RANGE TO MAX DOSE =0.2 DOSE AT GZ = 4111.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 3.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.5	24.5	3.1	15.5
30.	-0.4	18.7	2.2	11.6
100.	-0.3	12.8	1.4	7.5
300.	-0.3	8.0	0.8	4.0
1000.	-0.1	3.4	0.4	1.4
3000.	0.2	0.5	0.1	0.3
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 3148. RANGE TO MAX DOSE =0.3 DOSE AT GZ = 1910.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 5.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.4	36.2	2.6	22.9
30.	-0.3	26.9	1.8	16.5
100.	-0.3	17.5	1.1	9.9
300.	-0.2	10.0	0.6	4.6
1000.	-0.1	3.1	0.3	1.0
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 2191. RANGE TO MAX DOSE =0.3 DOSE AT GZ = 1238.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 10.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.3	60.5	2.1	37.9
30.	-0.2	42.7	1.3	25.6
100.	-0.2	25.4	0.8	13.1
300.	-0.1	11.8	0.4	6.0
1000.	0.1	1.5	0.1	0.3
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 1238. RANGE TO MAX DOSE =0.2 DOSE AT GZ = 658.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 20.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.2	98.3	1.6	60.2
30.	-0.2	65.0	1.0	36.5
100.	-0.1	33.4	0.5	18.2
300.	-0.1	10.1	0.1	4.5
1000.	0.	0.	0.	0.
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 664. RANGE TO MAX DOSE =0.2 DOSE AT GZ = 340.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.01000 MT WIND = 40.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.1	153.8	1.2	90.4
30.	-0.1	92.5	0.7	51.5
100.	-0.1	33.8	0.2	22.4
300.	0.	2.8	0.0	0.2
1000.	0.	0.	0.	0.
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 341. RANGE TO MAX DOSE =0.2 DOSE AT GZ = 173.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.03000 MT WIND = 1.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-1.1	15.3	8.6	9.7
30.	-1.0	12.2	6.4	7.6
100.	-0.8	9.0	4.4	5.4
300.	-0.7	6.3	2.9	3.5
1000.	-0.5	3.6	1.7	1.6
3000.	-0.2	1.5	0.8	0.6
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 4816. RANGE TO MAX DOSE =0.4 DOSE AT GZ = 3775.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.03000 MT WIND = 3.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.9	36.8	6.2	23.4
30.	-0.8	28.0	4.4	17.4
100.	-0.6	19.1	2.8	11.3
300.	-0.5	11.9	1.7	6.1
1000.	-0.2	5.1	0.8	2.0
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 2999. RANGE TO MAX DOSE =0.5 DOSE AT GZ = 1893.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.03000 MT WIND = 5.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.8	54.4	5.3	34.5
30.	-0.7	40.3	3.6	24.9
100.	-0.5	26.2	2.2	15.0
300.	-0.4	15.0	1.3	6.3
1000.	-0.1	4.7	0.5	1.6
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 2147. RANGE TO MAX DOSE =0.5 DOSE AT GZ = 1252.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = [illegible] MT WIND = 10.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.6	90.8	4.2	57.1
30.	-0.5	64.0	2.7	38.6
100.	-0.4	38.0	1.5	19.5
300.	-0.2	17.8	0.8	8.4
1000.	0.2	2.5	0.2	0.6
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 1252. RANGE TO MAX DOSE =0.5 DOSE AT GZ = 676.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.03000 MT WIND = 20.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.4	147.4	3.2	90.9
30.	-0.3	97.4	2.0	55.5
100.	-0.2	50.2	1.0	24.7
300.	-0.1	15.7	0.4	7.7
1000.	0.	0.	0.	0.
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 680. RANGE TO MAX DOSE =0.4 DOSE AT GZ = 351.

CALCULATED H+1 DOSE RATE CONTOURS
YIELD = 0.03000 MT WIND = 40.00 KTS
SHEAR = 0.100 KTS PER 1000 FT

DOSE ROENTGENS	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-0.2	230.5	2.4	137.1
30.	-0.2	138.6	1.4	68.3
100.	-0.1	52.1	0.5	32.1
300.	0.	5.4	0.1	0.3
1000.	0.	0.	0.	0.
3000.	0.	0.	0.	0.
10000.	0.	0.	0.	0.
30000.	0.	0.	0.	0.

MAX DOSE = 354. RANGE TO MAX DOSE =0.3 DOSE AT GZ = 179.

Appendix B

AFIT/WSEG Fortran Computer Program

This appendix contains the fully documented AFIT/WSEG Fortran computer code utilizing the subroutine Dose. It also contains a definition of terms for Dose and sample output for four different conditions. Disregard the computer generated sequencing at the left margin as it is not essential to the operation of the computer code.

```
      PROGRAM USEG(INPUT=/80,OUTPUT,TAPE5=OUTPUT)
      DIMENSION DHR(20),UPMAXI(20),DUDMAXI(20),YYMAXI(20)
      DIMENSION  R2MAXUI(20),CUMGXI(20)
      COMMON GT,GX,GT1
      COMMON OLDYLD,OLDWIND,OLDSHR,OLDX,OLDY,OLDFRAC
      COMMON T,ZN
C THIS PROGRAM IS THE AIR FORCE INSTITUTE OF TECHNOLOGY,S VERSION
C OF USEG-10 CREATED BY PUGH IN 1959 AND CONDENSED INTO PRESENT FORM
C --THE SUBROUTINE DOSE--OBTAINED FROM MR. RALPH MASON(NATIONAL
C MILITARY COMMAND SUPPORT CENTER).  INPUT AND OUTPUT PARAMETERS TO
C DOSE ARE EXPLAINED WITHIN DOSE AND NOT REPEATED HERE.  ADDITIONAL
C COMMENTS HAVE BEEN ADDED WITHIN DOSE TO TO FURTHER AID THE USER IN
C IDENTIFYING THE VARIABLES AND/OR THE PROCESS INVOLVED.
C
C THE MAIN PROGRAM IS DIVIDED INTO THREE SECTIONS:
C     1.  THE FIRST DO LOOP SEARCHES DOWNWIND OF GROUND ZERO FOR
C         MAXIMUM UNIT TIME REFERENCE DOSE RATE ECT.  IT ALSO CALCULATES
C         CUMULATIVE G(X) .
C     2.  THE SECOND DO LOOP SEARCHES UPWIND OF GROUND ZERO
C     3.  THE THIRD DO LOOP SEARCHES FOR CROSSRANGE DATA.  IT IS
C         ONLY CONCERNED WITH DOWNWIND DUE TO THE NATURE OF THIS MODEL.
C
C
C
C INPUTS ***************************************************************
C
C     FFRAC--REAL NUMBER SPECIFYING FISSION FRACTION FOR BURST
C
C     IYIELD--INTEGER PARAMETER SPECIFYING THE NUMBER OF YIELDS TO BE
C     EVALUATED.
C
C     ISHEAR--INTEGER SPECIFYING THE NUMBER OF SHEAR CONDITIONS.
C
C     IWIND--INTEGER SPECIVING THE NUMBER OF WIND CONDITIONS
C
C     IGT--INTEGER SPECIFYING OUTPUT INCLUDING G(T) AND TIME.  IF
C     DESIRED ENTER 1, IF NOT ENTER 0
C
C     IGX--INTEGER REQUESTING OUTPUT OF G(X) AND DOWNWIND DISTANCE.  IF
C     DESIRED ENTER 1, IF NOT ENTER 0
C
C     ICUMGX--INTEGER REQUESTING CUMULATIVE G(X) FOR EACH INPUT DOSE
C     RATED CONDITION.  IF DESIRED ENTER 1, IF NOT ENTER 0
C
C     XLEN--REAL NUMBER SPECIFYING THE DOWNWIND AND UPWIND MARCHING
C     INTERVAL.  THE UNITS ARE NAUTICAL MILES.
C
C     INT--INTEGER SPECIFYING WHICH ITERATION THE WRITE STATEMENTS FOR
C     G(X) AND G(T) ACT UPON.  I.E. IF INT=10 THEN EVERY TENTH VALUE OF
C     G(X)/G(T) AND DISTANCE/TIME WILL BE PRINTED.
C
C     YIELD--REAL NUMBER SPECIFYING THE YIELD OF THE WEAPON IN MEGATONS.
C
C     WIND--REAL NUMBER SPECIFYING THE EFFECTIVE WIND IN KNOTS.
C
C     SHEARY--REAL NUMBER SPECIFYING THE CROSSWIND SHEAR COMPONENT IN
C     KNOTS/KILOFOOT.
C
C     DH1--REAL NUMBER SPECIFYING THE UNIT TIME REFERENCE DOSE RATE
C     THE COMPUTER WILL USE AS IT GENERATES THE OUTPUT PARAMETERS.
C
```

```
C
C
C  OUTPUT$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C     INITIAL CONDITIONS--YIELD,WIND,SHEAR,FISSION FRACTION,STEP SIZE
C
C     G(X)--DEPOSITION OF FALLOUT PER LINEAR MILE.  THE UNITS ARE PER
C     NAUTICAL MILE.  INCLUDED IS CORRESPONDING RANGE FROM GROUND
C     ZERO.
C
C     G(T)--DEPOSITION OF FALLOUT EVERYWHERE PER TIME.  THE UNITS ARE
C     PER HOUR.  ACCOMPANYING G(T) IS ITS TIME COORDINATE IN HOURS.
C
C     DWDMAX--DISTANCE IN NAUTICAL MILES FROM GROUND ZERO DOWNWIND TO
C     UTRD RATE SPECIFIED BY DHI.
C
C     UPMAX--UPWIND DISTANCE TO UTRD RATE SCECIFIED BY DHI FROM GROUND
C     ZERO.  THE UNITS ARE NAUTICAL MILES.  NOTE XX MAY BE (-) OR (+)
C     DEPENDING ON THE MAGNITUDES OF THE EFFECTIVE WIND AND YIELD.
C
C     DBMAX--MAXIMUM HOTLINE UTRD RATE CONTAINED WITHIN THE TOTAL
C     FALLOUT PATTERN SPECIFIED BY THE MINIMUM DHI.  UNITS ARE R/HOUR.
C
C     RMAXD--DISTANCE FROM GROUND ZERO IN NAUTICAL MILES TO DBMAX.
C
C     DGZ--UTRD RATE AT GROUND ZERO.  THE UNITS ARE R/HOUR.
C
C     YYMAX--MAXIMUM CROSSRANGE WIDTH OF ISO-DOSE RATE CONTOUR SPECIFIED
C     BY DHI.  THE UNITS ARE NAUTICAL MILES.
C
C     R2MAXW--DOWNWIND OR UPWIND DISTANCE TO YYMAX.  UNITS ARE NAUTICAL
C     MILES.
C
C     CUMGX--CUMULATIVE G(X) BOUNDED BY THE UPWIND AND DOWNWIND RANGE
C     DATA SPECIFIED BY DHI.  CUMGX CALCULATED BY TRAPEZOIDAL INTEG-
C     RATION AND IS DIMENSIONLESS.
C
C     "N"--EXPONENT OF G(X) OR G(T)
C
C     "T"--TIME CONSTANT FOR YIELD
C
C
C
C
      READ*,FFRAC
      SIGYA2=0.0
      DO 10 J=1,20
          DHR(J)=0.0   SUPMAXI(J)=0.0   $ YYMAXI(J)=0.0
          R2MAXWI(J)=0.0   $ DWDMAXI(J)=0.0   $ CUMGXI(J)=0.0
10    CONTINUE
      READ*,IYIELD,ISHEAR,IWIND,IGT,IGX,ICUMGX
      READ*,XLEN,INT
      DO 14 JK=1,IYIELD
      READ*,YIELD
      DO 14 JKK=1,ISHEAR
      READ*, SHEARY
      DO 14 KJK=1,IWIND
      READ*,WIND
      WRITE 25
```

```
25    FORMAT(1X,*CALCULATED H+1 HOUR DOSE RATE CONTOURS*,//)
      WRITE 30
30    FORMAT(1X,*INITIAL CONDITIONS:*,/)
      WRITE 35,YIELD
35    FORMAT(5X,*YIELD(MEGATONS)*,10X,*= *,F6.2,/)
      WRITE 50,FFRAC
50    FORMAT(5X,*FISSION FRACTION*,9X,*= *,F6.2,/)
      WRITE 55,WIND
55    FORMAT(5X,*WIND(KTS)*,16X,*= *,F6.2,/)
      WRITE 60,SHEARY
60    FORMAT(5X,*SHEAR(KTS PER KILOFOOT)*,2X,*= *,F6.2,/)
      WRITE 64,XLEN
64    FORMAT(5X,*STEP SIZE(NAUTICAL MILE)*,* =  *,F6.3,/)
      WRITE 65
65    FORMAT(1X,*RESULTS:  ALL DISTANCES IN NAUTICAL MILES*,//)
      IF(IGT.EQ.1)  WRITE 66
66    FORMAT(10X,'G(T)',15X,'G(T)*PHI',14X,'TIME')
      IF(IGT.EQ.1)  WRITE 67
67    FORMAT(7X,*PER HOUR*,14X,*PER HOUR*,14X,*HOURS*,//)
      IF(WIND.EQ.0.0.AND.IGT.EQ.1)  PRINT*,'G(T) AND TIME ARE FUNCTIONS
     'OF WIND AND DISTANCE AND ARE EITHER UNDEFINED OR 0.0'
      IF(IGX.EQ.1) WRITE 68
68    FORMAT(7X,*G(X)*,15X,*HOTLINE*)
      IF(IGX.EQ.1)  WRITE 69
69    FORMAT(5X,*PER NAUT.MI.*,6X,*FROM GRD.ZERO*,//)
      DBMAX=0.0
      DO 4 JJ=1,8
      CUMGX=0.0
      UPMAX=0.0
      XX=0.0
      YY=0.0
      OLDFRAC=0.0
      OLDY=1.E9
      OLDX=1.E9
      OLDSHR=1.E9
      OLDWIND=1.E9
      OLDYLD=0.0
      DHOLD=0.0
      DH=1.E9
      READ*,DHI
      DO 1 I=1,6000
         KL=(I/INT)*INT
         CALL DOSE(DB,DH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,YIELD)
         IF(YY.EQ.0..AND.XX.EQ.0.)  DGZ=DH
         IF(DH.LT.DHI.AND.I.EQ.1)  DWDMAX=0.0
         IF(DH.LT.DHI.AND.I.EQ.1)  YYMAX=0.0
         IF(DH.LT.DHI.AND.I.EQ.1)  R2MAXW=0.0
         IF(DH.LT.DHI.AND.I.EQ.1)  CUMGX=0.0
         IF(DH.GE.DBMAX)  DBMAX=DH
         IF(DH.GE.DBMAX)  RMAXD=XX
         IF(DH.GE.DHI.AND.DH.LE.DHOLD)   DWDMAX=XX
         IF(DH.LE.DHI.AND.DH.GE.DHOLD.AND.DBMAX.GE.DHI)  UPMAX=XX
         IF(DH.LT.DHI.AND.DH.LT.DHOLD)  GO TO 5
         IF(I.GT.1)  AV=(GXOLD+GX)/2.
         IF(I.GT.1)  CUMGX=AV*XLEN+CUMGX
         GXOLD=GX
         IF(WIND.EQ.0.0)  TIME=0.0
         IF(WIND.GT.0.0)  TIME=XX/WIND
         IF(JJ.GT.1)  GO TO 9
         IF(WIND.NE.0.0.AND.IGT.EQ.1.AND.KL.EQ.I)  WRITE 70,GT,GT1,TIME
```

```
70    FORMAT(3X,F12.8,10X,F12.8,12X,F6.2)
      IF(KL.EQ.I.AND.IGX.EQ.1)    WRITE 71,GX,XX
71    FORMAT(3X,F12.8,10X,F6.2)
9     IF(DBMAX.LT.DHI)  GO TO 5
      DHOLD=DH
      XX=XX+XLEN
1   CONTINUE
    IF(DH.GT.DHI.AND.I.EQ.6000)  WRITE 72,DHI
72  FORMAT(10X,F6.0,10X,*CALCULATIONS INCOMPLETE---PLEASE INCREASE
   'STEP SIZE*,/)
    IF(DH.GT.DHI.AND.I.EQ.6000)  GO TO 15
5   XX=0.0
    YY=0.0
    IF(IGX.EQ.1.AND.JJ.EQ.1) PRINT*,' '
    IF(IGX.EQ.1.AND.JJ.EQ.1)  PRINT*,'IN THE UPWIND DIRECTION:'
    IF(IGX.EQ.1.AND.JJ.EQ.1) PRINT*,' '
    OLDYLD=0.0
    OLDWIND=1.E9
    OLDSHR=1.E9
    OLDX=1.E9
    OLDY=1.E9
    OLDFRAC=0.0
    DH=DBMAX
    DO 2 I=1,6000
      KL=(I/INT)*INT
      IF(DH.LT.DHI.AND.I.GE.2)  GO TO 7
      CALL DOSE(DB,DH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,YIELD)
      IF(DH.GE.DHI)   UPMAX=XX
      IF(DH.LT.DHI.AND.I.EQ.1.AND.UPMAX.EQ.0.0)  UPMAX=0.0
      IF(DH.GE.DBMAX)  DBMAX=DH
      IF(DH.GE.DBMAX)  RMAXD=XX
      IF(I.GT.1)  AV=(GXOLD+GX)/2.
      IF(I.GT.1)  CUMGX=AV*XLEN+CUMGX
      GXOLD=GX
      IF(JJ.GT.1)  GO TO 6
      IF(KL.EQ.I.AND.IGX.EQ.1)    WRITE 71,GX,XX
6     XX=XX-XLEN
2   CONTINUE
7   XX=0.0
    YY=0.0
    OLDFRAC=0.0
    YYOLD=0.0
    OLDY=1.E9
    OLDX=1.E9
    OLDSHR=1.E9
    OLDWIND=1.E9
    OLDYLD=0.0
    DHII=-DHI
    DO 3 I=1,6000
      IF(XX.GT.DWDMAX)  GO TO 11
      CALL DOSE(YDB,YDH,DHII,YY,XX,SHEARY,WIND,FFRAC,YIELD)
      IF(YDH.GE.YYOLD)  YYMAX=YDH
      IF(YDH.GE.YYOLD)  R2MAXW=XX
      YYOLD=YDH
      XX=XX+XLEN
3   CONTINUE
11  R2MAXWI(JJ)=R2MAXW      $CUMGXI(JJ)=CUMGX
    DWDMAXI(JJ)=DWDMAX      $ YYMAXI(JJ)=YYMAX
    DHR(JJ)=DHI       $UPMAXI(JJ)=UPMAX
4   CONTINUE
```

```
      IF(ICUMGX.EQ.1)  WRITE 73
73    FORMAT(//,10X,*DOSE RATE*,10X,*MAXIMUM*,10X,*MAXIMUM*,10X,*MAXIMUM
     '*,10X,*RANGE TO*,10X,*CUMULATIVE*)
      IF(ICUMGX.EQ.1)  GO TO 12
      WRITE 74
74    FORMAT(//,10X,*DOSE RATE*,10X,*MAXIMUM*,10X,*MAXIMUM*,10X,*MAXIMUM
     '*,10X,*RANGE TO*)
12    IF(ICUMGX.EQ.1)  WRITE 75
75    FORMAT(8X,*ROENTGENS/HR*,9X,*UPWIND*,11X,*DOWNWIND*,9X,*CROSSWIND*
     ',8X,*MAX WIDTH*,12X,*G(X)*,/)
      IF(ICUMGX.EQ.1) GO TO 13
      WRITE 76
76    FORMAT(8X,*ROENTGENS/HR*,9X,*UPWIND*,11X,*DOWNWIND*,9X,*CROSSWIND*
     ',8X,*MAX WIDTH*,/)
13    DO 8 K=1,8
          IF(ICUMGX.NE.1)  WRITE 80,DHR(K),UPMAXI(K),DWDMAXI(K),YYMAXI(K
     '    ),R2MAXWI(K)
80        FORMAT(10X,F6.0,13X,F6.2,11X,F6.2,11X,F6.2,12X,F6.2,/)
          IF(ICUMGX.EQ.1) WRITE 81,DHR(K),UPMAXI(K),DWDMAXI(K),YYMAXI(K)
     '    ,R2MAXWI(K),CUMGXI(K)
81        FORMAT(10X,F6.0,13X,F6.2,11X,F6.2,11X,F6.2,12X,F6.2,12X,F8.6,
     '    /)
8     CONTINUE
      PRINT*,' '
      WRITE 85,DBMAX
85    FORMAT(5X,*MAXIMUM DOSE RATE*,11X,*=*,2X,F6.0,/)
      WRITE 90,RMAXD
90    FORMAT(5X,*RANGE TO MAXIMUM DOSE RATE  =  *,F5.1,/)
      WRITE 95,DGZ
95    FORMAT(5X,*DOSE RATE AT GROUND ZERO    =  *,F6.0,/)
      WRITE 100,ZN
100   FORMAT(5X,*PARAMETER 'N'*,15X,*=*,2X,F6.4,/)
      WRITE 105,T
105   FORMAT(5X,*TIME CONSTANT*,15X,*=*,2X,F7.4,///)
14    CONTINUE
15    STOP 'END OF PROGRAM'
      END
      SUBROUTINE DOSE(DB,DH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,YIELD)
      COMMON GT,GX,GT1
      COMMON OLDYLD,OLDWIND,OLDSHR,OLDX,OLDY,OLDFRAC
      COMMON T,ZN
C
C     THIS SUBROUTINE IS THE FEBRUARY 23,1962 VERSION WITH ALL CHANGES/
C     MODIFICATIONS TO RESEARCH MEMORANDUM 10 INCORPORATED.  USERS WILL
C     BE INFORMED OF ANY LATER MODIFICATIONS.
C     IN NORMAL FULL CALLS.
C
C     OUTPUT PARAMETERS -----------------------------------
C
C        DB=THE BIOLOGICAL DOSE IN ROENTGENS FOR AN INFINITE PLANE DOSE.
C
C        DH=THE H+1 HOUR DOSE RATE IN ROENTGENS/HOUR FOR AN INFINITE PLA
C        DOSE.
C
C        SIGYA2=THE TERM SIGMA Y SQUARED IN SQUARE NAUTICAL MILES.
C          (SOMETIMES USEFUL IN INTEGRATION OF DOSE AREAS)
C
C
C     INPUT PARAMETERS-----------------------------------
C
```

```
C        YY=THE CROSSWIND DISTANCE PERPENDICULAR TO THE WIND DIRECTION
C        IN NAUTICAL MILES.
C
C        XX=DISTANCE ALONG THE HOTLINE PARALLEL TO THE WIND DIRECTION
C        IN NAUTICAL MILES.  (XX IS NEGATIVE FOR UPWIND LOCATIONS)
C
C        SHEARY=THE CROSSWIND COMPONENT OF SHEAR.
C
C        WIND=THE EFFECTIVE FALLOUT WIND IN KNOTS.
C
C        FFRAC=THE FISSION FRACTION.
C
C        YIELD=THE YIELD IN MEGATONS.
C
C
C     NOTE THAT CALCULATIONS ARE NOT REPEATED FOR PARAMETERS THAT HAVE
C     NOT CHANGED.  THEREFORE, THE CALL MAY BE SHORTENED TO EXCLUDE
C     THOSE PARAMETERS AT THE END OF THE CALLING SEQUENCE THAT REMAIN
C     THE SAME.
C        FOR EXAMPLE:   CALL DOSE(DB,DH,SIGYA2,YY)
C
C
C     A SECOND USE IS TO INPUT XX AND UTRD RATE AND RECEIVE AS OUTPUT
C     CORRESPONDING YY IN NAUTICAL MILES.  (USEFUL IN COMPUTATION OF
C     FALLOUT CONTOURS).
C     FOR EXAMPLE:
C        CALL DOSE(YDH,YDB,-DOSE,YY,XX,SHEARY,WIND FFRAC,YIELD)
C
C        YDH=THE YY DISTANCE IN NAUTICAL MILES FOR AN H+1 INPUT DOSE.
C
C        YDB=THE YY DISTANCE IN NAUTICAL MILES FOR A BIOLOGICAL DOSE.
C
C        -DOSE=MINUS THE VALUE OF THE DOSE.
C
C        ALL OTHER PARAMETERS ARE THE SAME AS ABOVE.
C
C
C     NOTE NAUTICAL MILES ARE CONVERTED TO STATUTE MILES IN DOSE
C     THE CONVERSION FACTOR = 1.151515 STATUTE MILES PER NAUTICAL MILE
C
C
C
C
C
C     YIELD DEPENDENT EQUATIONS ***************************
      IF(YIELD-OLDYLD) 1,2,1
1     OLDYLD=YIELD
      YMT=ALOG(YIELD)
      T3=2000000.*YIELD
      SIGO=.7+YMT/3.-3.25/(4.+(YMT+5.4)**2)
C  INITIAL STABILIZED CLOUD RADIUS
      SIGO=EXP(SIGO)
      SIGO2=SIGO*SIGO
      T1=YMT+2.42
C  CLOUD CENTER HEIGHT IN KILOFEET
      H=44.+6.1*YMT-.205*T1*ABS(T1)
C  VERTICLE STANDARD DEVIATION
      SIGH=.18*H
      SIGH2=SIGH*SIGH
      T2=H/60.
```

```
C   TIME CONSTANT
       T=(12.*T2-2.5*T2*T2)*(1.-.5*EXP(-(H/25.)**2))*1.0573203
       GO TO 3
2      IF(WIND-OLDWIND)  3,5,3
C      WIND DEPENDENT CALCULATIONS ************************
3      OLDWIND=WIND
4      ZLO=WIND*T*1.151515
       ZLO2=ZLO*ZLO
       SIGX2=SIGO2*(ZLO2+8.*SIGO2)/(ZLO2+2.*SIGO2)
C   STANDARD DEVIATION FOR X DIRECTION
       SIGX=SIGX2**.5
       ZL2=ZLO2+2.*SIGX2
C   PARAMETER 'L'
       ZL=ZL2**.5
       T14=ZLO2+.5*SIGX2
C   THE PARAMETER 'N'
40     ZN=(ZLO2+SIGX2)/T14
       IF(ZN-1.002)  102,102,103
102    ZN=1.
       T20=1.
       GO TO 42
C   GAMMA(1.+1./ZN) FOLLOWS:
103    T20=GAMMA(1./ZN)
42     T4=T3/(ZL*T20*2.50663)
       PALPH=.001*H*WIND*1.151515/SIGO
C   ALPH1 IS A CORRECTION FACTOR FOR CUMULATIVE NORMAL ARGUEMENT
       ALPH1=1./(1.+PALPH)
       T5=ZLO/(ZL*ALPH1*SIGX)
       T6=2.*SIGX2*T*T*SIGH2/ZL2
       T15=ZLO2/ZL2
       T7=T15*T*T*SIGH2
       GO TO 6
C      SHEAR DEPENDENT CALCULATIONS ************************
5      IF(SHEARY-OLDSHR)  6,8,6
6      OLDSHR=SHEARY
7      T21=SHEARY*SHEARY*1.325975
       T8=T6*T21
       T9=T7*T21/ZL2
       GO TO 9
C      X DEPENDENT CALCULATIONS ****************************
8      IF(XX-OLDX)  9,116,9
9      OLDX=XX
       X=XX*6080./5280.
C   T10 INTRODUCES ASYMMETRY (MOST NOTICABLE FOR '0' WIND AND '0' SHEAR
C   CONDITION) WHEN COUPLED WITH THE CRITERIA FOR T11.  T10 SHOULD
C   READ:  T10=ABS(X)+2.*SIGX
10     T10=X+2.*SIGX
       T11=1.+(8.*ABS(T10))/ZL
       IF(T11-4.)  12,12,11
11     T11=4.
12     T22=T11*SIGO2
       T30=T5*X
       IF(T30-6.)  35,36,36
36     T30=1.
       GO TO 37
35     T30=CUMNOR(T30)
37     T12=T9*T10*T10
43     IF(X)  13,14,13
14     T13=1.
       GO TO 15
```

```
13      IF(ZN-1.)  113,114,113
114     T13=EXP(-(ABS(X)/ZL))
        GO TO 15
113     T13=EXP(-(ABS(X)/ZL)**ZN)
15      SIGY2=T22+T8+T12
C  STANDARD CROSSRANGE DEVIATION
        SIGY=SIGY2**.5
C  TIME OF ARRIVAL OF FALLOUT AFTER BURST
        TAPR=(.25+(T15*T10*T10*T*T+2.*SIGX2)/T14)**.5
        BETA=ALOG(TARR/31.6)
        ZLD=-.287-.52*BETA-.04475*BETA*BETA
C  CONVERSION FACTOR TO CHANGE DH+1 HOUR DOSE RATE TO ABSORBED DOSE
        BIO=EXP(ZLD)
C G(X) IS THE EXPRESSION DEFINED BY SCHMIDT ON PAGE 4
        GX=1.151515*(T30*T13)/(ZL*T20)
C THE FOLLOWING G(T) IS OBTAINED BY MULTIPLYING G(X) BY WIND
        GT=1.151515*(WIND*T13)/(ZL*T20)
C  THE FOLLOWING EXPRESSION IS G(T) MULTIPLIED BY THE CUMULATIVE NORMAL
C  FUNCTION
        GT1=GT*T30
        IF(WIND)  27,27,53
53      T23=(2.*X)/(WIND*1.151515)
        IF(T23-10.)  28,28,27
27      ALPH22=1.
        GO TO 29
28      T24=CUMNOR(T23)
C  ALPH22 IS A CORRECTION FACTOR FOR CROSSRANGE GAUSSIAN DISTRIBUTION
        ALPH22=1./(1.+PALPH*(1.-T24))
29      ALPH2=ALPH22*ALPH22
        IF(SIGYA2)  91,90,90
C       TO CALCULATE Y, GIVEN X AND A DOSE
90      SIGYA2=SIGY2*ALPH2
        GO TO 17
91      DHXO=T30*T13*T4*FFRAC/SIGY
        DBXO=DHXO*BIO
        DOSEL=ABS(SIGYA2)
        IF(DOSEL)  95,117,95
95      IF(DHXO/DOSEL-1.)  94,94,92
94      DH=0.
        GO TO 93
117     DH=0.
        DB=0.
        RETURN
C  THIS STEP CALCULATES YY GIVEN AN INPUT DOSE RATE AND XX
92      DH=ALPH22*SIGY*SQRT(2.*ALOG(DHXO/DOSEL))*5280./6080.
C  THIS STEP CALCULATES YY GIVEN AN INPUT DOSE AND XX
93      DB=ALPH22*SIGY*SQRT(2.*ABS(ALOG(DBXO/DOSEL)))*5280./6080.
        RETURN
116     IF(SIGYA2)  91,16,16
C       Y DEPENDENT CALCULATIONS ****************************
16      IF(YY-OLDY)  17,19,17
17      OLDY=YY
        Y=YY*6080./5280.
C  CROSSRANGE GAUSSIAN DISTRIBUTION FUNCTION
18      T16=EXP(-.5*Y*Y/(ALPH2*SIGY2))/SIGY
        GO TO 22
19      IF(FFRAC-OLDFRAC)  20,22,20
20      OLDFRAC=FFRAC
21      DH=DDH*FFRAC
        DB=DDB*FFRAC
```

```
      RETURN
22    DDH=T30*T16*T13*T4
      DDE=DDH*BIO
      GO TO 20
      END
      FUNCTION GAMMA(TM)
C GAMMA FUNCTION APPROXIMATED FROM HASTINGS P.156
      GAMMA=1.+TM*(-0.57669867+TM*(0.97781781+TM*(-0.8235627+TM*(
     '0.67399080+TM*(-0.3282793+TM*0.07673206)))))
      RETURN
      END
      FUNCTION CUMNOR(TA)
C  CUMULATIVE NORMAL APPROXIMATED FROM HASTINGS P. 186
      TM=ABS(TA/1.414213562)
      TMP=1.+TM*(.14112821+TM*(.08864027+TM*(.02743340+TM*(-.00039446+
     'TM*.00328975))))
      TMP=TMP**8
      SUM=1.-1./TMP
      IF(TA.LT.0.)GO TO 1
C  THIS STEP INTEGRATES THE NORMAL DISTRIBUTION FUNCTION FROM
C  INFINITY TO ZERO.  THIS ALLOWS A MAXIMUM AT GROUND ZERO.
      CUMNOR=.5*(1.+SUM)
      GO TO 2
1     CUMNOR=.5*(1.-SUM)
2     RETURN
      END
```

CALCULATED H+1 HOUR DOSE RATE CONTOURS

INITIAL CONDITIONS:

YIELD(MEGATONS) = .01

FISSION FRACTION = 1.00

WIND(KTS) = 1.00

SHEAR(KTS PER KILOFOOT) = .10

STEP SIZE(NAUTICAL MILE) = .050

RESULTS: ALL DISTANCES IN NAUTICAL MILES

DOSE RATE ROENTGENS/HR	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-.50	10.10	4.20	6.45
30.	-.45	8.10	3.14	5.05
100.	-.40	5.95	2.15	3.65
300.	-.30	4.15	1.43	2.40
1000.	-.20	2.40	.83	1.10
3000.	-.05	1.00	.43	.35
10000.	0.00	0.00	0.00	0.00
30000.	0.00	0.00	0.00	0.00

MAXIMUM DOSE RATE = 5531.

RANGE TO MAXIMUM DOSE RATE = .2

DOSE RATE AT GROUND ZERO = 4110.

PARAMETER 'N' = 1.0034

TIME CONSTANT = 2.2966

CALCULATED H+1 HOUR DOSE RATE CONTOURS

INITIAL CONDITIONS:

YIELD(MEGATONS)	=	.01
FISSION FRACTION	=	1.00
WIND(KTS)	=	3.00
SHEAR(KTS PER KILOFOOT)	=	.10
STEP SIZE(NAUTICAL MILE)	=	.050

RESULTS: ALL DISTANCES IN NAUTICAL MILES

DOSE RATE ROENTGENS/HR	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH	CUMULATIVE G(X)
10.	-.40	24.40	3.06	15.55	.970948
30.	-.35	18.60	2.16	11.60	.932614
100.	-.25	12.70	1.37	7.55	.841318
300.	-.20	7.90	.83	4.00	.681615
1000.	-.05	3.35	.41	1.40	.381651
3000.	.15	.40	.07	.25	.047853
10000.	0.00	0.00	0.00	0.00	0.000000
30000.	0.00	0.00	0.00	0.00	0.000000

MAXIMUM DOSE RATE	=	3153.
RANGE TO MAXIMUM DOSE RATE	=	.3
DOSE RATE AT GROUND ZERO	=	1910.
PARAMETER 'N'	=	1.0000
TIME CONSTANT	=	2.2966

CALCULATED H+1 HOUR DOSE RATE CONTOURS

INITIAL CONDITIONS:

YIELD(MEGATONS) = .01

FISSION FRACTION = 1.00

WIND(KTS) = 5.00

SHEAR(KTS PER KILOFOOT) = .10

STEP SIZE(NAUTICAL MILE) = .050

RESULTS: ALL DISTANCES IN NAUTICAL MILES

G(T) PER HOUR	G(T)*PHI PER HOUR	TIME HOURS
.28289962	.28289962	.99
.18305547	.18305547	1.99
.11844945	.11844945	2.99
.07664492	.07664492	3.99
.04959452	.04959452	4.99
.03209106	.03209106	5.99
.02076512	.02076512	6.99

DOSE RATE ROENTGENS/HR	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-.30	36.15	2.60	22.90
30.	-.25	26.80	1.78	16.50
100.	-.20	17.45	1.09	9.95
300.	-.15	9.95	.63	4.55
1000.	0.00	3.00	.25	1.00
3000.	0.00	0.00	0.00	0.00
10000.	0.00	0.00	0.00	0.00
30000.	0.00	0.00	0.00	0.00

MAXIMUM DOSE RATE = 2193.

RANGE TO MAXIMUM DOSE RATE = .3

DOSE RATE AT GROUND ZERO = 1238.

PARAMETER "N" = 1.0000

TIME CONSTANT = 2.2966

CALCULATED H+1 HOUR DOSE RATE CONTOURS

INITIAL CONDITIONS:

YIELD(MEGATONS)	=	.01
FISSION FRACTION	=	1.00
WIND(KTS)	=	10.00
SHEAR(KTS PER KILOFOOT)	=	.10
STEP SIZE(NAUTICAL MILE)	=	.050

RESULTS: ALL DISTANCES IN NAUTICAL MILES

G(X) PER NAUT.MI.	HOTLINE FROM GRD.ZERO
.02981068	8.70
.02036670	17.45
.01391455	26.20
.00950644	34.95
.00649481	43.70
.00443726	52.45

IN THE UPWIND DIRECTION:

DOSE RATE ROENTGENS/HR	MAXIMUM UPWIND	MAXIMUM DOWNWIND	MAXIMUM CROSSWIND	RANGE TO MAX WIDTH
10.	-.20	60.40	2.06	37.85
30.	-.15	42.65	1.35	25.55
100.	-.10	25.35	.77	13.10
300.	-.05	11.70	.37	6.00
1000.	.05	1.45	.10	.25
3000.	0.00	0.00	0.00	0.00
10000.	0.00	0.00	0.00	0.00
30000.	0.00	0.00	0.00	0.00

MAXIMUM DOSE RATE	=	1244.
RANGE TO MAXIMUM DOSE RATE	=	.3
DOSE RATE AT GROUND ZERO	=	658.
PARAMETER "N"	=	1.0000
TIME CONSTANT	=	2.2966

SUBROUTINE DOSE

DEFINITION OF FORTRAN TERMS

Inputs:

YY	=	Crosswind distance in nautical miles
XX	=	Downwind distance in nautical miles
SHEARY	=	Crosswind component of shear in knots/kilofeet
WIND	=	Effective fallout wind in knots
FFRAC	=	Fission fraction
YIELD	=	Yield in megatons

Conversion from nautical to statute miles:

$$\frac{6080}{5280} = 1.151515 \text{ and } (1.151515)^2 = 1.325975$$

Terms:

YMT = $\ell n(\text{yield})$

T3 = $2 \times 10^6 \cdot \text{yield} \rightarrow (\frac{\text{R-mi}^2}{\text{hr}})$ (SNC . yield)*

SIGO = $\sigma_o = \exp(.7 + \frac{\ell n(\text{yield})}{3} - 3.25/(4. + (\ell n(\text{yield}) + 5.4)^2)$ (statute miles)

SIGO2 = σ_o^2 (statute miles)^2

T1 = $\ell n(\text{yield}) + 2.42$ (used in "H" calculation)

H = $H_c = 44. + 6.1\ \ell n(\text{yield}) - .205\ (\ell n(\text{yield}) + 2.42) \cdot |\ell n(\text{yield}) + 2.42|$ (kilofeet)

*Roentgens abbreviated by "R".

SIGH	=	$\sigma_h = .18H$	(kilofeet)
SIGH2	=	σ_h^2	(kilofeet)
T2	=	H/60	(dimensionless)
T=T_c	=	$(1.0573203)(12(H/60) - 2.5\ (H/60)^2)\ \cdot$ $(1 - .5\ \exp-(H/25)^2)$	(hours)
ZLO	=	L_o = Wind (T) (1.151515)	(statute miles)
ZLO^2	=	L_o^2	(statute miles)^2
SIGX2	=	σ_x^2	(statute miles)^2
	=	$\sigma_o^2 \left(\frac{L_o + 8\sigma_o^2}{L_o + 2\sigma_o^2}\right)$	
SIGX	=	σ_x	(statute miles)
ZL2	=	$L^2 = L_o^2 + 2\sigma_x^2$	(statute miles)^2
ZL	=	L	(statute miles)
T14	=	$L_o^2 + .5\sigma_x^2$	(statute miles)^2
ZN	=	$n = \left(\frac{L_o^2 + \sigma_x^2}{L_o^2 + .5\sigma_x^2}\right)^2$	(dimensionless)
T20	=	1.	
		or	
T20	=	GAMMA(1. + 1/ZN)	(dimentionless)
T4	=	$\frac{2 \times 10^6\ (\text{yield})}{L\ \Gamma(1 + \frac{1}{n})\ \sqrt{2\pi}}$	$\left(\frac{\text{R-statute miles}}{\text{hour}}\right)$
PALPH	=	$\frac{.001(H)(\text{Wind})(1.151515)}{\sigma_o}$	(dimensionless)

$$\text{ALPH1} = \alpha_1 = \frac{1.}{1 + \frac{.001(H)(Wind)(1.151515)}{\sigma_o}}$$

(dimensionless)

$$T5 = \frac{L_o}{(L\alpha_1\sigma_x)}$$ (per statute mile)

$$T6 = \frac{2\sigma_x{}^2T^2\sigma_h{}^2}{L^2}$$ (hr^2 kilofeet^2)

$$T15 = \frac{L_o{}^2}{L^2}$$ (dimensionless)

$$T7 = \frac{L_o{}^2}{L^2}\ T^2\sigma_h{}^2$$ (hr^2 - kilofeet $)^2$

$$T8 = \frac{2\sigma_x{}^2T^2\sigma_h{}^2(\text{Sheary})^2(1.325975)}{L^2}$$ (statute miles)^2

$$T9 = \frac{L_o{}^2T^2\sigma_h{}^2(\text{Sheary})^2(1.325975)}{L^4}$$ (dimensionless)

X = Downwind distance in statute miles = x

$T10 = x + 2\sigma_x$ (statute miles)

$T11 = 1 + (8|x + 2\sigma_x|)/L$

or (dimensionless)

$T11 = 4.$

$T22 = 4\sigma_o{}^2$

or (statute miles)^2

$T22 = (1 + 8|x + 2\sigma_x|)/L)\sigma_o{}^2$

$T30 = \text{Cumnor}(1.) = \phi(1.)$

or (dimensionless)

$$\text{T30} = \text{Cumnor}\left(\frac{L_o x}{L\alpha_1\sigma_x}\right) = \phi\left(\frac{L_o x}{L\alpha_1\sigma_x}\right)$$

$$\text{T12} = \frac{(L_o T\sigma_h \text{Sheary}(1.151515))^2}{L^4}(x + 2\sigma_x)^2$$

(statute miles)^2

$$\text{T13} = 1.$$

or

$$\text{T13} = \exp - \left(\frac{|x|}{L}\right) \qquad \text{(dimensionless)}$$

or

$$\text{T13} = \exp - \left(\frac{|x|}{L}\right)^n$$

$$\text{SIGY2} = \sigma_y^2 = \sigma_o^2\left(1 + \frac{8|x + 2\sigma_x|}{L}\right) + \frac{2(\sigma_x T\sigma_h \text{Sheary}(1.151515))^2}{L^2} + \frac{((x + 2\sigma_x)L_o T\sigma_h \text{Sheary}(1.151515))^2}{L^4}$$

(statute miles)^2

$$\text{SIGY} = \sigma_y = (\text{SIGY2})^{1/2} \qquad \text{(statute miles)}$$

$$\text{TARR} = t_a = \left(.25 + \frac{\left(\frac{L_o^2}{L}(x + 2\sigma_x)^2 T^2 + 2\sigma_x^2\right)}{L_o^2 + .5\sigma_x^2}\right)^{1/2}$$

(hours)

$$\text{BETA} = \ell n\left(\frac{t_a}{31.6}\right) \qquad \text{(dimensionless)}$$

$$\text{ZLD} = -.287 - .52\ell n\left(\frac{t_a}{31.6}\right) - .04475\left(\ell n\left(\frac{t_a}{31.6}\right)^2\right)$$

(dimensionless)

$$\text{BIO} = \exp-(.287 + .52\ell n(\frac{t_a}{31.6}) + .04475\ \ell n(\frac{t_a}{31.6})^2)$$

(hours)

$$\text{T23} = \frac{(2x)}{\text{Wind}(1.151515)} \quad \text{(hours)}$$

If $\text{T23} = 10 \quad \text{Alph22} = \alpha_2 = 1$ (dimensionless)

$$\text{T24} = \text{Cumnor}(\frac{2x}{\text{Wind}(1.151515)}) \quad \text{(dimensionless)}$$

If T23 < 10:

$$\text{Alph22} = \alpha_2 = \frac{1}{1 + \frac{(.001(H)(\text{Wind})(1.151515)}{\sigma_o}(1-\text{Cumnor}(\frac{2x}{\text{Wind}}))}$$

(dimensionless)

$$\text{Alph2} = \alpha_2{}^2 \quad \text{(dimensionless)}$$

$$\text{SIGYA2} = \sigma_y{}^2\alpha_2{}^2 \quad \text{(statute miles)}^2$$

$$\text{DHXO} = \text{Cumnor}\ (\frac{L_o x}{L\alpha_1\sigma_x})\ \exp - (\frac{|x|}{L})^n \ .$$

$$\frac{(2 \times 10^6(\text{yield})\text{FFRAC})}{L\Gamma(1 + 1/n)\sqrt{2\pi}\sigma_y} = f_x \quad \text{(R/hr)}$$

$$\text{DBXO} = \text{DHXO} \times \text{BIO} \quad \text{(R/hr)}$$

$$= \text{Cumnor}\ (\frac{L_o x}{\alpha_1 L\sigma_x})\ \exp = (\frac{|x|}{L})^n \ .$$

$$\frac{(2 \times 10\ )\text{yield}(\text{FFRAC})}{L\Gamma(1 + 1/n)\sqrt{2\pi}\sigma_y} \ . \ \text{BIO}$$

DH = H + 1 Dose Rate (R/hr)

DB	=	Biological Dose	(R)
Y	=	Crosswind distance in statute miles = y	
T16	=	$\exp -\frac{1}{2}\left(\frac{y^2}{\alpha_2{}^2\sigma_y{}^2}\right) = f_y$	(per statute miles)

$$DDH = \text{Cumnor}\left(\frac{L_o x}{L\alpha_1\sigma_x}\right)\frac{\exp -\frac{1}{2}\left(\frac{y^2}{\alpha_2{}^2\sigma_y{}^2}\right)}{\sigma_y}\exp -\left(\frac{|x|}{L}\right)^n$$

$$\frac{(2 \times 10^6)\text{yield}}{L\Gamma(1 + 1/n)\sqrt{2\pi}} = \frac{f_x \cdot f_y}{\text{fission fraction}} =$$

$$\frac{D_{H+1}}{FFRAC} \qquad (R/hr)$$

DDB	=	DDH x BIO	(R)
DH	=	0	(R/hr)

or

$$\text{Cumnor}\left(\frac{L_o x}{L\alpha_1\sigma_x}\right)\frac{\exp -\frac{1}{2}\left(\frac{y^2}{\alpha_2{}^2\sigma_y{}^2}\right) 2 \times 10^6(\text{yield})FFRAC\exp -\left(\frac{|x|}{L}\right)^n}{\sigma_y L\Gamma(1 + 1/n)\sqrt{2\pi}}$$

or

YDH =

$$\frac{\alpha_2\sigma_y}{1.151515}\left(2\ln\left(\frac{\text{Cumnor}\left(\frac{L_o x}{L\alpha_1\sigma_x}\right)\exp -\frac{1}{2}\left(\frac{|x|}{L}\right)^n(2 \times 10\ )\text{yield}(FFRAC)}{(\text{Input } D_{H+1})(L)\Gamma(1 + 1/n)\sqrt{2\pi}\ \sigma_y}\right)\right)^{\frac{1}{2}}$$

(nautical miles)

DB	=	0	(ERDS or R)

or

$$DB = DDB \cdot FFRAC$$

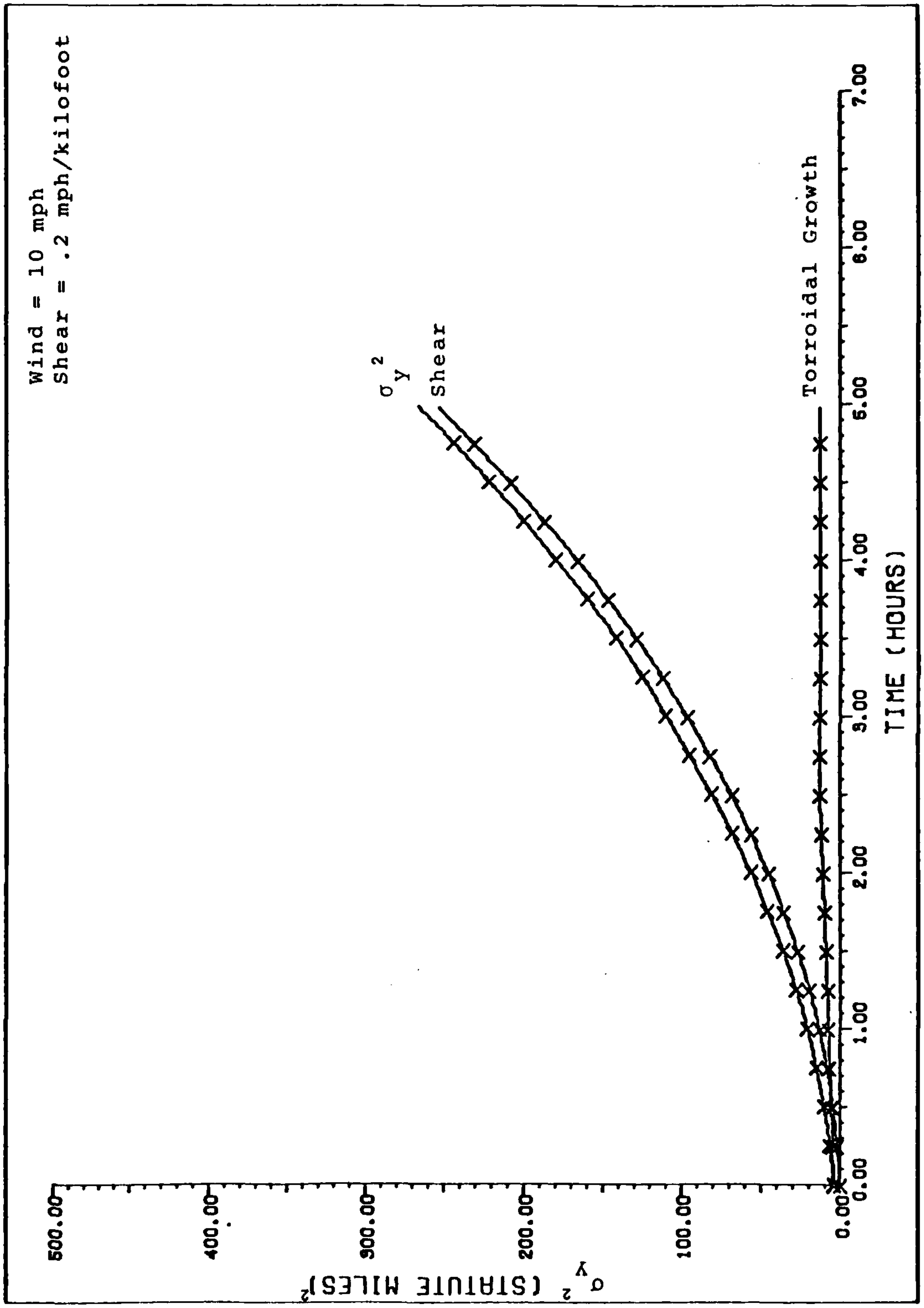
or

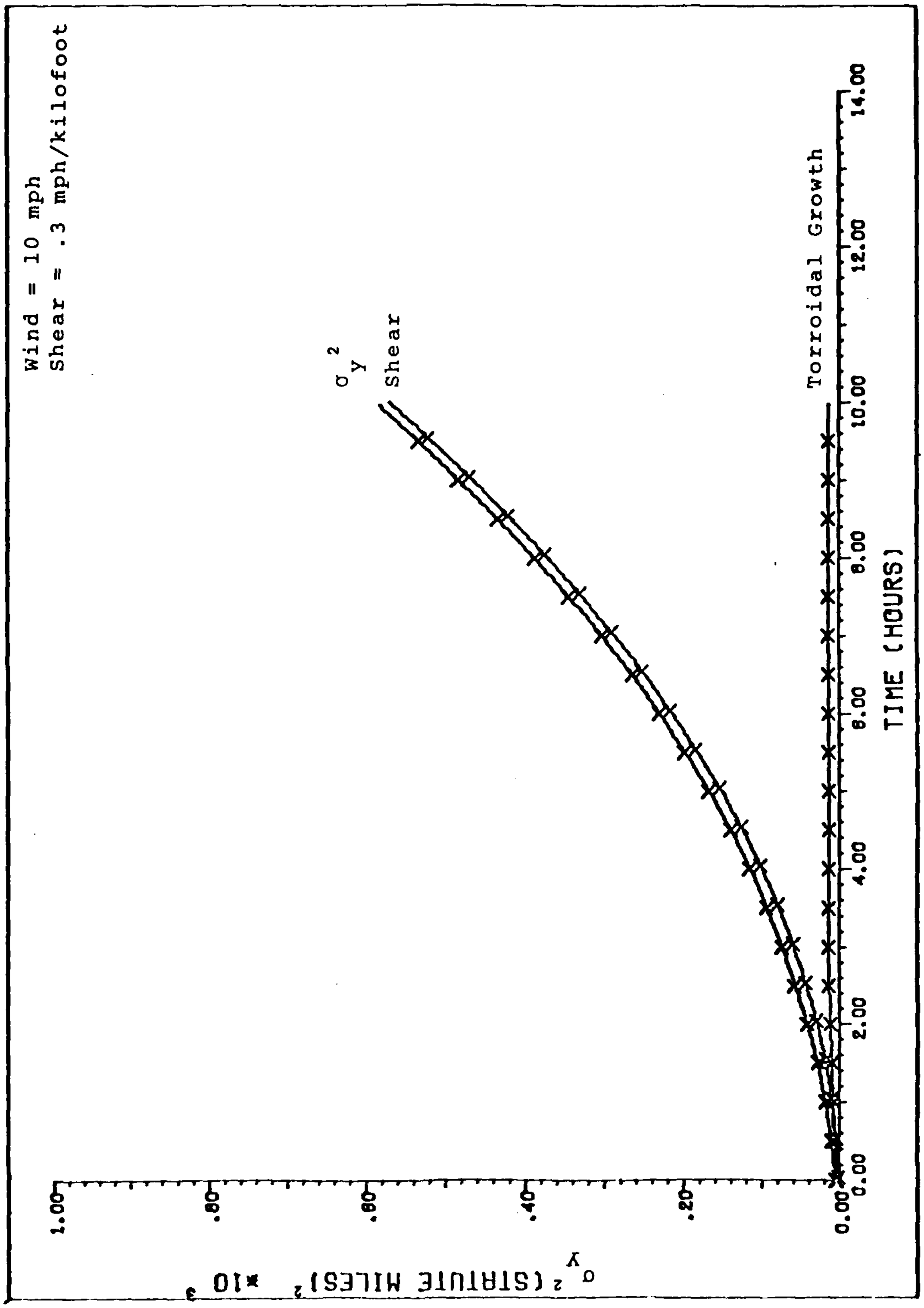
$$YDB = \frac{\alpha_2 \sigma_y}{1.151515} \left(2 \ln \left(\frac{DHXO \cdot BIO}{Input\ Dose}\right)\right)^{\frac{1}{2}} \quad \text{(nautical miles)}$$

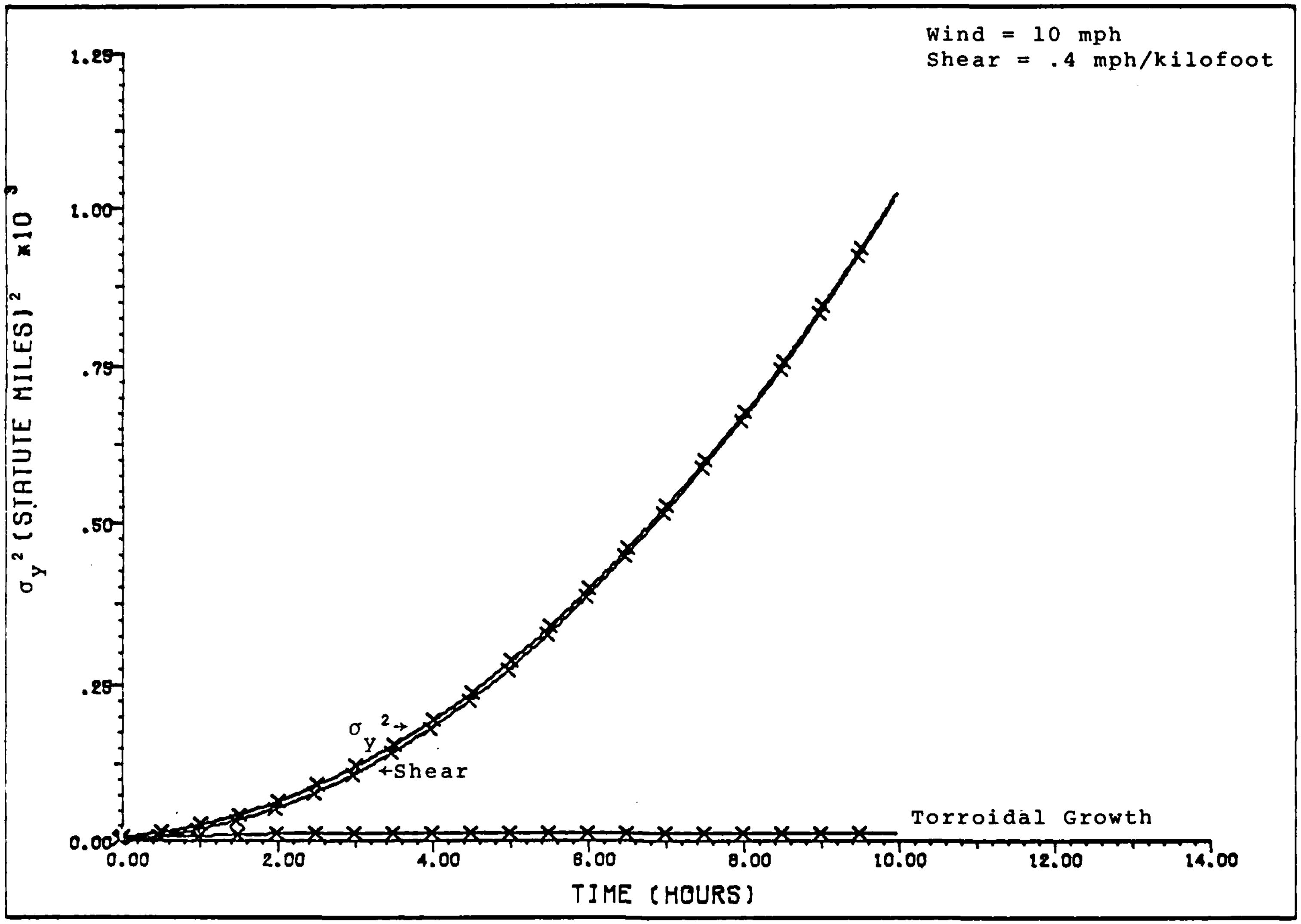
Appendix C

Comparison of Terms Influencing Crossrange Dispersion

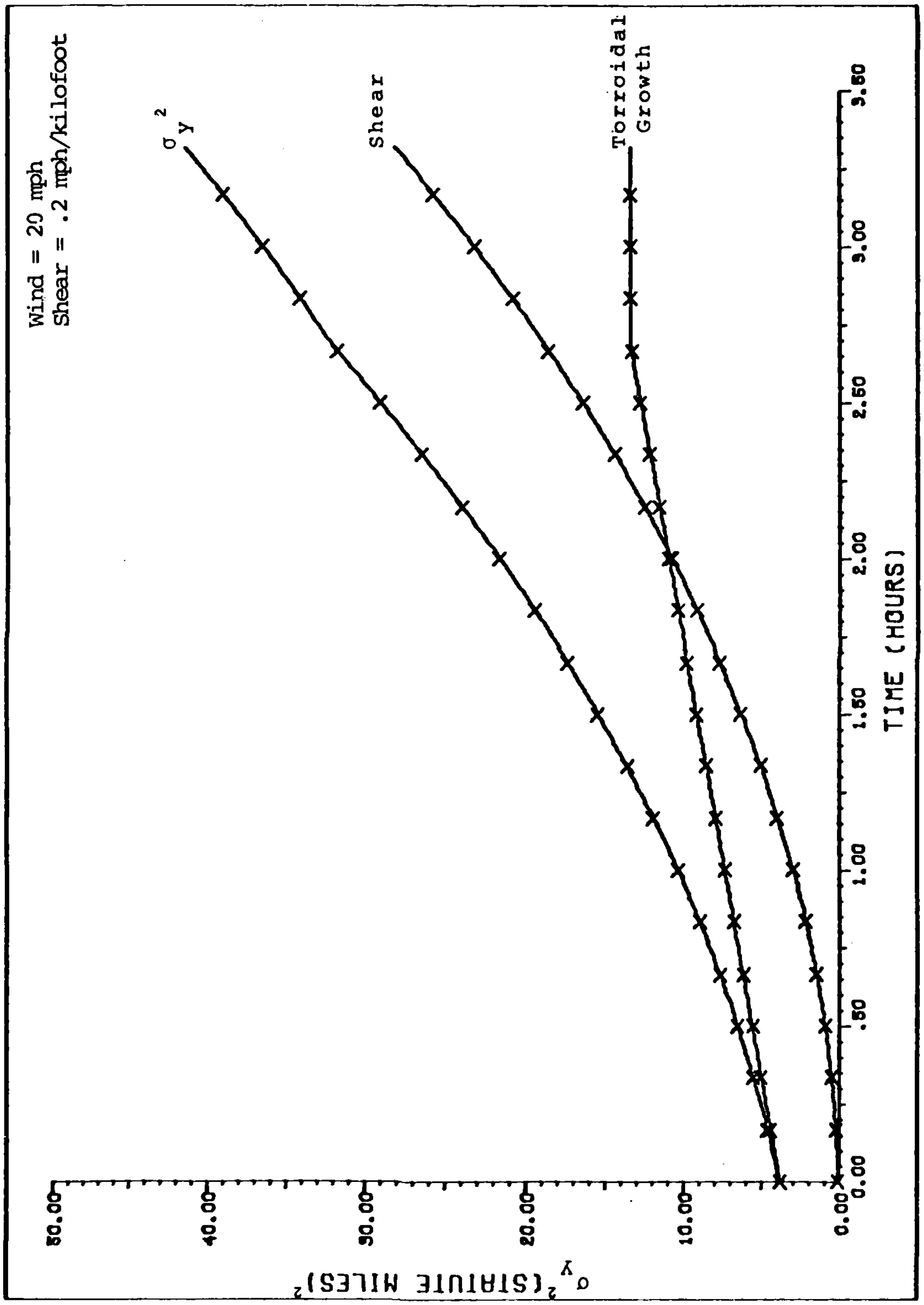
This appendix contains graphical comparisons of the effects of shear and torroidal growth on σ_y^2. The torroidal growth and shear effects are plotted versus time. The graphs contained within this appendix are meant to supplement Section III, Figures 6-8. As is the case for Figures 6-8, the yield is 10 MT and the fission fraction = 1.0. The units $\frac{\text{st.mi.}}{\text{hr}}$ will be abbreviated as mph on all graphs contained in this section.


Wind = 10 mph
Shear = .2 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
σ_y^2 (STATUTE MILES)^2
TIME (HOURS)
0.00
100.00
200.00
300.00
400.00
500.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

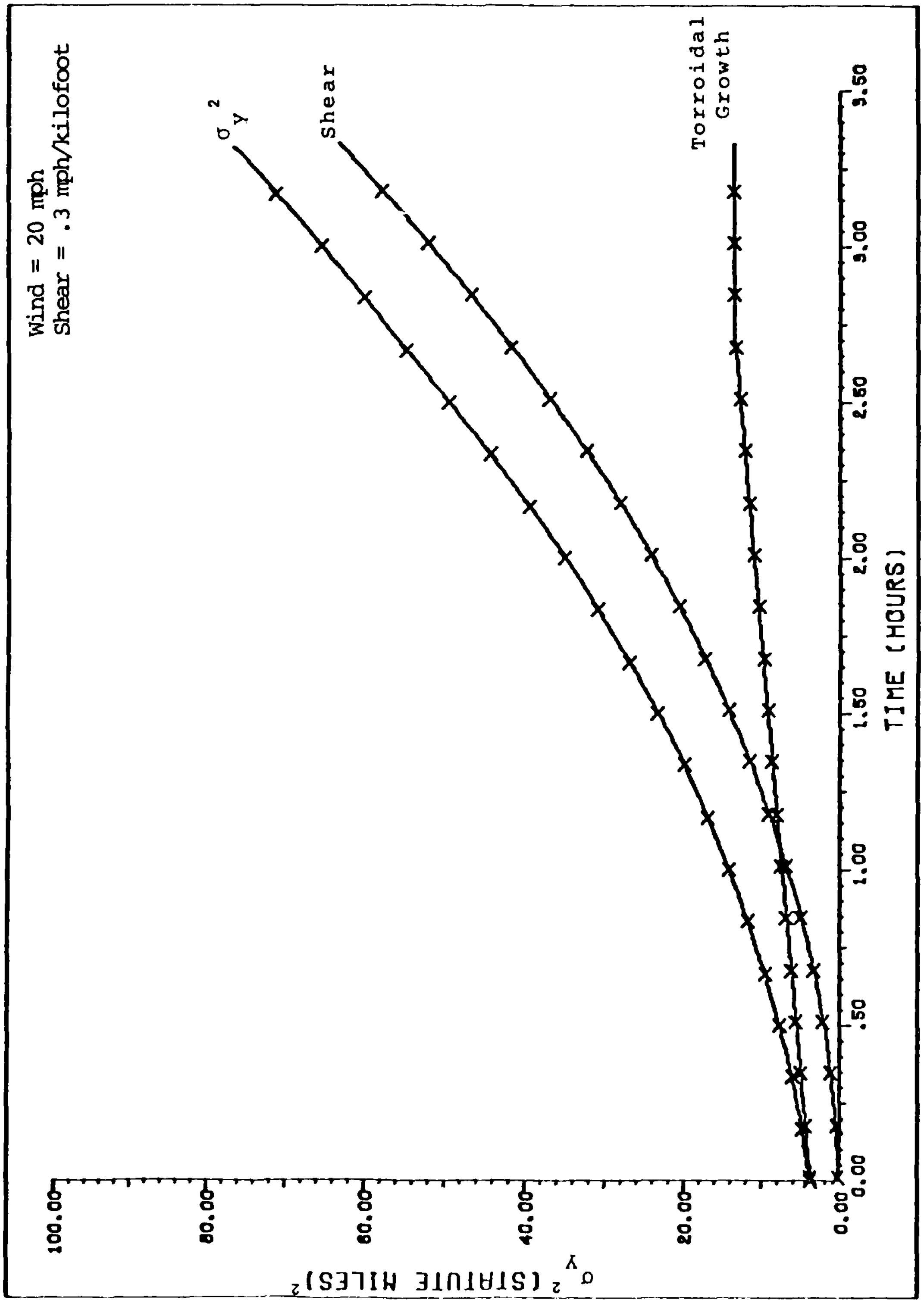

Wind = 10 mph
Shear = .3 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
TIME (HOURS)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
0.00
.20
.40
.60
.80
1.00
σ_y^2 (STATUTE MILES)^2 ×10^3



Wind = 10 mph
Shear = .4 mph/kilofoot
σy² (STATUTE MILES)² ×10³
1.25
1.00
.75
.50
.25
0.00
σy²→
←Shear
Torroidal Growth
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME (HOURS)



Wind = 20 mph
Shear = .2 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
0.00
10.00
20.00
30.00
40.00
50.00
σ_y^2(STATUTE MILES)^2
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
TIME (HOURS)


Wind = 20 mph
Shear = .3 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
σ_y^2 (STATUTE MILES)^2
0.00
20.00
40.00
60.00
80.00
100.00
TIME (HOURS)
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50

AD-A083 515 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 9/2
DOCUMENTATION AND ANALYSIS OF THE WSEG-10 FALLOUT PREDICTION MO--ETC(U)
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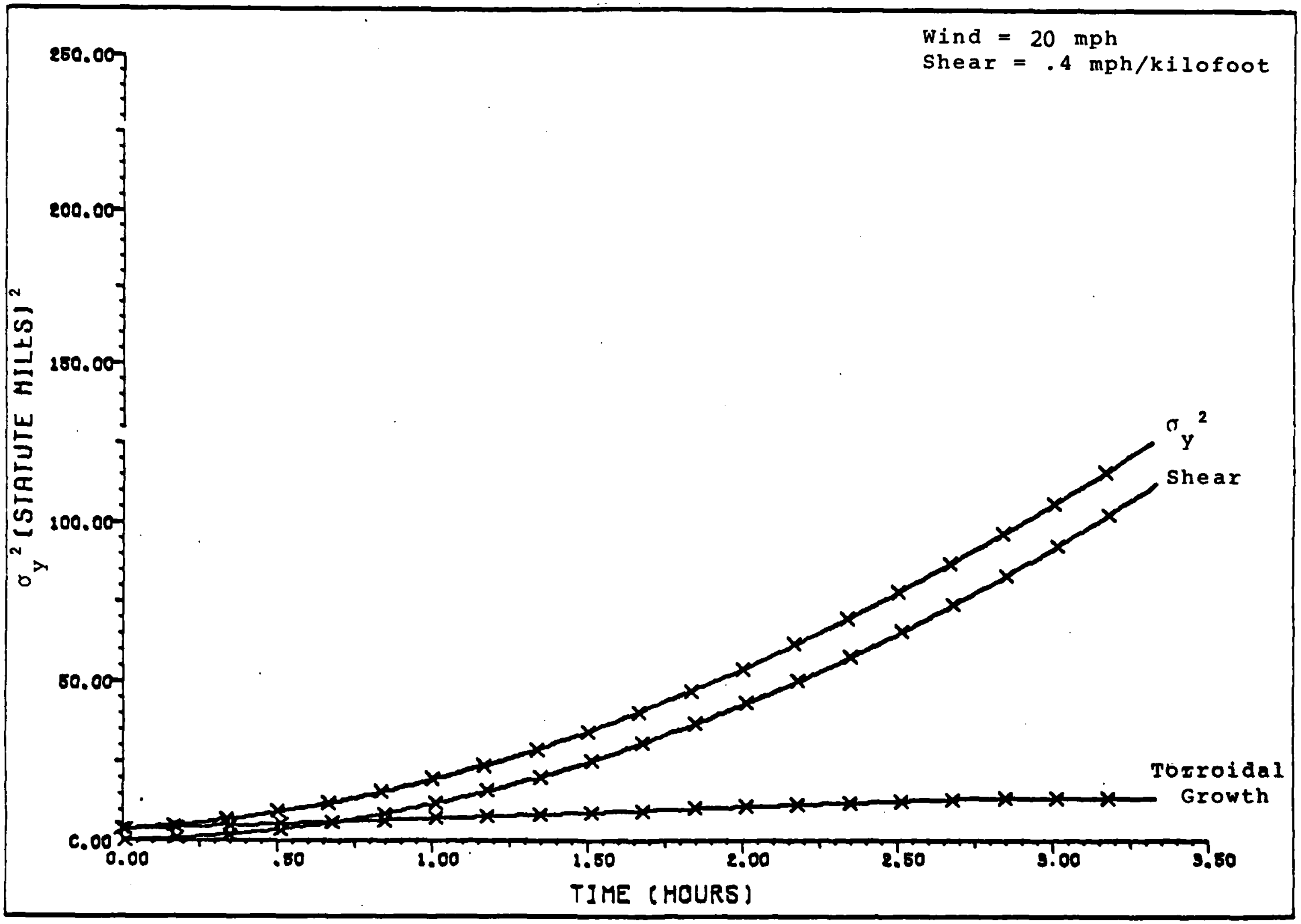
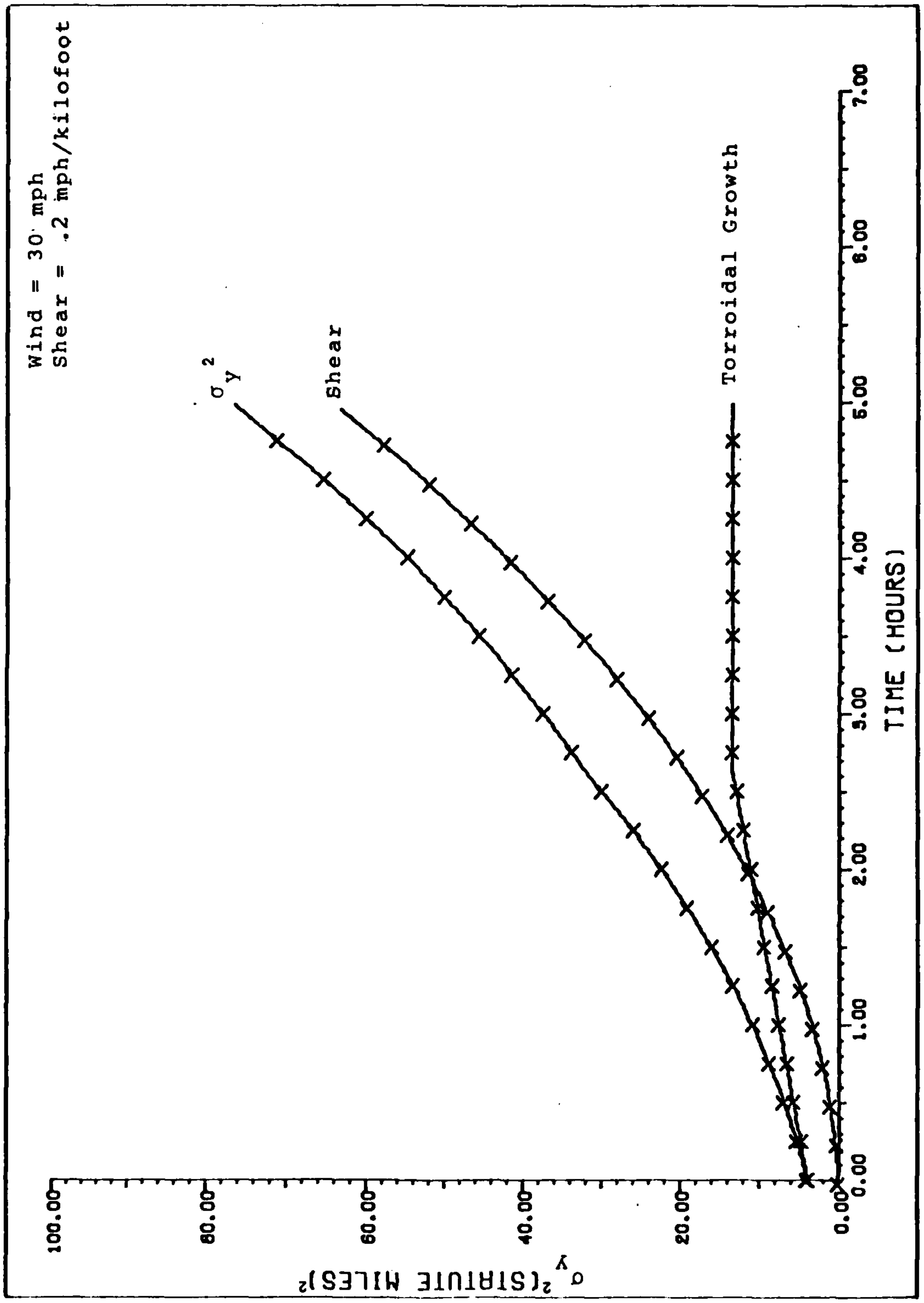
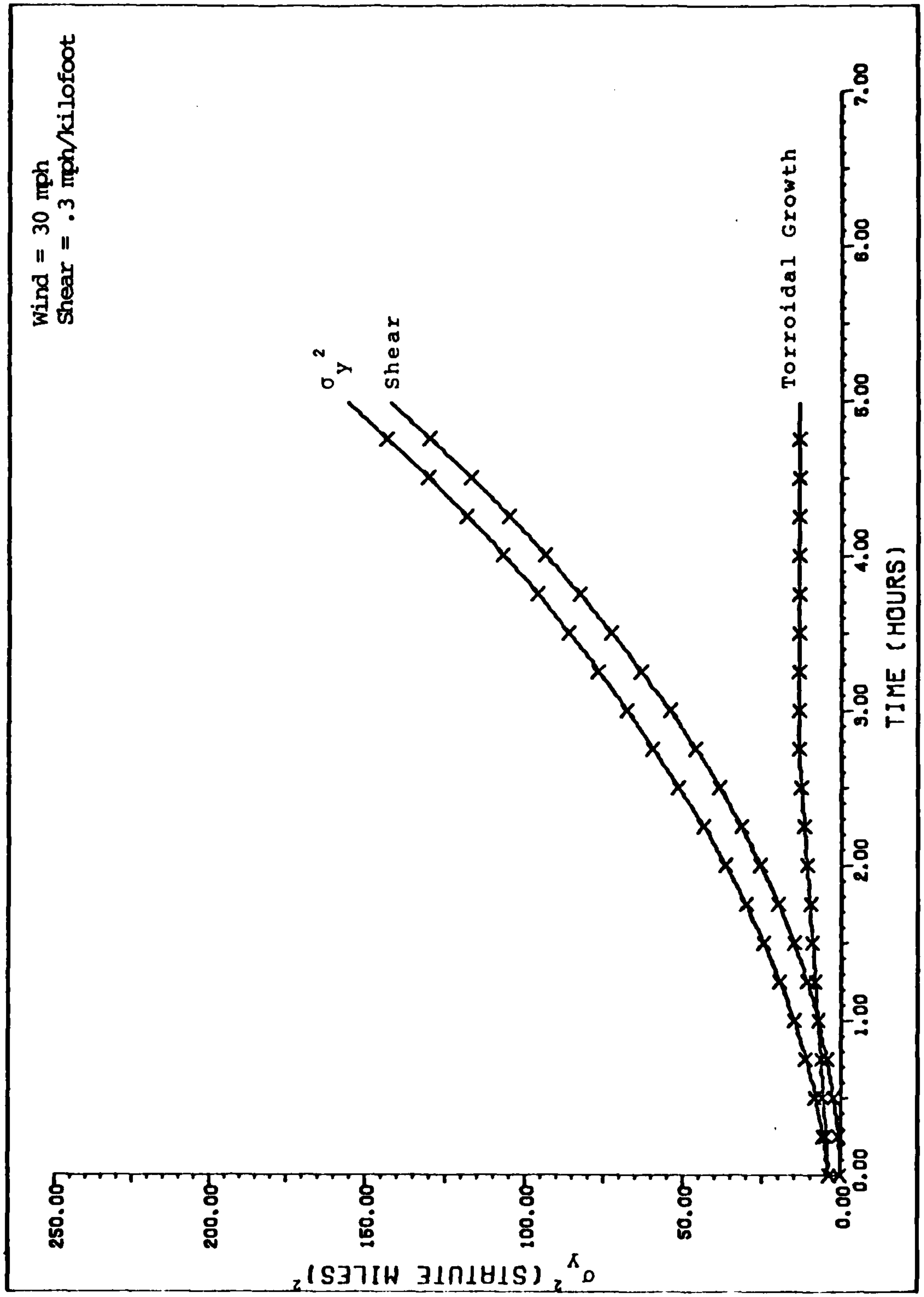
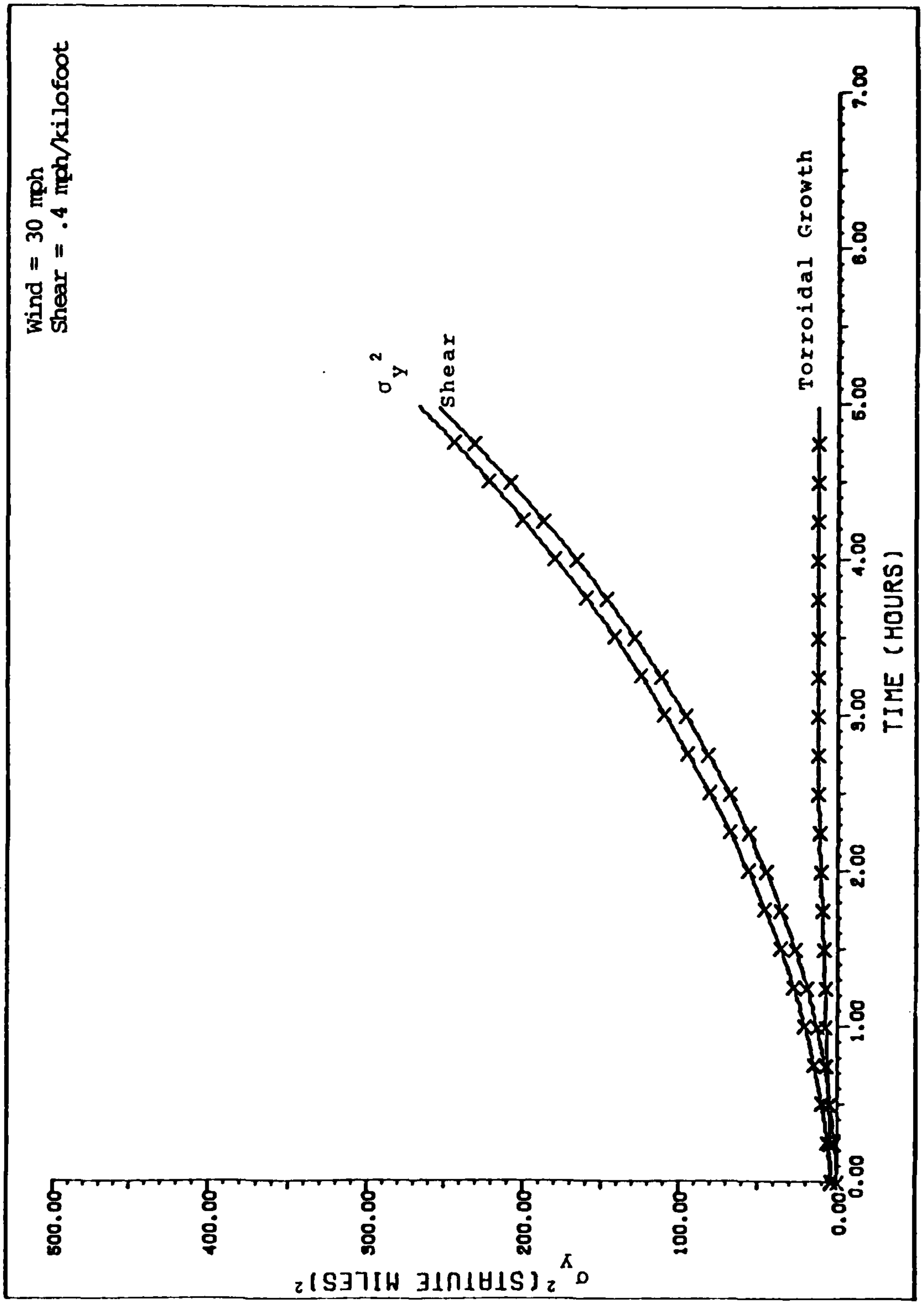

Wind = 20 mph
Shear = .4 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
250.00
200.00
150.00
100.00
50.00
0.00
σ_y^2 (STATUTE MILES)^2
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
TIME (HOURS)


Wind = 30 mph
Shear = .2 mph/kilofoot
σy 2
Shear
Torroidal Growth
σy 2(STATUTE MILES)2
100.00
80.00
60.00
40.00
20.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
TIME (HOURS)


Wind = 30 mph
Shear = .3 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
TIME (HOURS)
σ_y^2 (STATUTE MILES)^2
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
50.00
100.00
150.00
200.00
250.00



Wind = 30 mph
Shear = .4 mph/kilofoot
σ_y^2
Shear
Torroidal Growth
TIME (HOURS)
σ_y^2 (STATUTE MILES)^2
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
100.00
200.00
300.00
400.00
500.00

Appendix D

Derivation of Diffusivity from Fick's Law

Assume fallout cloud has one size particle with average velocity $V(\frac{st.mi.}{hr})$. Consider a differential volume in spherical coordinates dVOL where:

$$N(r,t) = \text{particle number density } (\frac{\#particles}{dVOL})$$

and:

$$\text{Flux} = F = N \cdot V \; (\frac{\#particles - st.mi.}{hour})$$

Initial condition:

$$N(r,0) = 0$$

$$\frac{\partial N(r,t)}{\partial t} = -\text{Leakage} - \text{Absorption} + \text{Source} = -\nabla \cdot J_{net}$$

and:

$$J_{net} = -D\nabla(F) = -D\nabla(NV)$$

$$\frac{\partial N(r,t)}{\partial t} = \nabla D\nabla(NV) = \nabla D\nabla F = \nabla^2 F$$

In circular geometry:

$$\frac{\partial N(r,t)}{\partial t} = D(\frac{\partial^2 N(r,t)}{\partial r^2} + \frac{2}{r}\frac{\partial N(r,t)}{\partial r})$$

$$= D\partial^2 \frac{N(r,t)}{\partial r^2} + \frac{2}{r} D \frac{N(r,t)}{\partial r}$$

To solve, use Laplace Transforms. Let:

$$\mathcal{L}\{N(r,t)\} \equiv \tilde{N}(r,s)$$

then: $\mathcal{L}\{\frac{\partial N(r,t)V}{\partial t}\} = sN(r,s) - \tilde{N}(r,o)$

From the initial condition $N(r,0) = 0$ when:

$$t = 0$$

$$s = 0$$

and let: $D_v = D \cdot V$

Therefore:

$$s\tilde{N} = D_v N'' + \frac{2D_v \tilde{N}'}{r}$$

where

$$\tilde{N}' = \frac{d\tilde{N}(r,s)}{dr}$$

or

$$\tilde{N}'' + \frac{2}{r} N' - \frac{s}{D_v}\tilde{N} = 0$$

s assumed constant and the solution =

$$\tilde{N}(r,s) = \frac{C_1}{r} e^{-\sqrt{\frac{s}{D_v}}r} + \frac{C_2}{r} e^{+\sqrt{\frac{s}{D_v}}r}$$

C_2 is assumed 0 for stability. To convert back to time, form 82 (Ref. 12: 497) is used on the following expression:

$$\tilde{N}(r,s) = \frac{C_1}{r} e^{-\frac{r}{\sqrt{D_v}}(\sqrt{s})}$$

where

$$K = \frac{r}{\sqrt{D_v}}$$

Resulting in: $N(r,t) = \frac{C_1}{2\sqrt{D_v} \cdot \sqrt{\pi t^3}} e^{-(\frac{r^2}{4D_v t})}$

If forced to resemble Gaussian distribution of the form

$$\frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{r}{\sigma^2}\right)^2}$$

where r and σ have dimensions of length. Then:

$$C = \frac{\sqrt{t}}{2\sqrt{\pi D_v}}$$

and $$\sigma^2 = 2D_v t \quad \text{(area)}$$

If some initial radius present at t = 0, then:

$$\sigma_f^{\,2} = \sigma_i^{\,2} + 2D_v t \quad \text{(area)}$$

Appendix E

Computer Program User's Guide

The purpose of this Appendix is to describe, from a user's point of view, the Fortran computer code employing the WSEG analytical expressions to generate iso-dose rate contours. Specifically, this discussion will concentrate on the Fortran code generated during this thesis to reproduce the sample results contained in Appendix A.

The discussion is divided between the main program and the subroutine Dose. The complete code is contained in Appendix B along with a definition of terms for the subroutine. Sample output for several options is also included. Much of what is said here has been incorporated within the AFIT/WSEG program in Appendix B as comments to aid the user should this thesis be unavailable for reference.

Subroutine Dose

The subroutine Dose (hereafter referred to as "Dose") contains in compact form the coded WSEG expressions discussed within this thesis. It is nearly identical to the original subroutine contained in Appendix A and obtained from Mr. Ralph Mason. Minor modifications to several expressions were necessary to make the code compatible with the ASD CYBER 74 computer system to correct obvious typographical mistakes. User instructions are contained within Dose as comments.

In general, Dose can perform two functions depending on the input parameters. First, Dose can compute a D_{H+1} or

Biological Dose based upon the inputs of effective wind, shear, fission fraction, yield, crossrange coordinate, and downrange coordinate. This assumes a ground zero at "0" crossrange and "0" downrange.

The input parameters are:

YY = Crossrange coordinate in nautical miles.

XX = Downwind (+x) or upwind (-x) coordinate in nautical miles.

SHEARY = Average shear in knots/kilofeet.

WIND = Effective wind in knots.

SIGYA2 = Any real number greater than 0. Not used when calculating D_{H+1} or Biological Dose.

The call to the subroutine is a standard Fortran call to a subroutine:

```
Call Dose (DB,DH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,YIELD)
```

The output parameters are:

DB = Biological Dose in ERDS

DH = D_{H+1} in Roentgens/hr

The second function Dose can perform is to generate a crossrange coordinate based upon a downrange coordinate and a given Biological Dose or D_{H+1}. Dose solves for the crossrange coordinate by solving the following expression for Y:

$$-\text{Input } D_{H+1} = f_x \cdot \frac{\exp -\frac{1}{2}\left(\frac{Y^2}{\alpha_2 \sigma_y}\right)^2}{\sqrt{2\pi}\sigma_y} \qquad (33)$$

$$\text{or} \quad -\text{Input Biological Dose} = f_x \cdot \text{Bio} \cdot \frac{\exp -\frac{1}{2}\left(\frac{y}{\alpha_2 \sigma_y}\right)^2}{\sqrt{2\pi}\sigma_y} \tag{34}$$

where f_x is defined by Equation (22). Since the fallout pattern is nearly elliptical, the crossrange coordinate is either (+) or (-) yielding the same result. In either case, the input parameters are:

YY = Any real number. Not used in this option.

XX = Downwind (+x) or upwind (-x) coordinate in nautical miles.

SHEARY = Average shear in knots/kilofeet.

WIND = Effective wind in knots.

SIGYA2 = -Biological Dose or $-D_{H+1}$

The call for the subroutine is also a standard Fortran subroutine call:

```
Call Dose (YDB,YDH,SIGYA2,YY,XX,SHEARY,WIND,FFRAC,YIELD)
```

The output parameters are:

YDB = Crossrange distance in nautical miles corresponding to an input Biological Dose.

YDH = Crossrange distance in nautical miles corresponding to an input D_{H+1}

Originally Dose did not compute specific functions known as g(x), g(t), or ϕ.g(x) but these expressions are used implicitly. This program was modified for this the is to compute

g(t), g(x), ϕ.g(t), and cumulative ϕ.g(x) and makes them available as output via common statements where G(X) = g(x), G(T) = g(t) and CUMGX = cumulative ϕ.g(x).

Main Program

The main program (WSEG) contains two separate sections. The first section describes the purpose of the program, the necessary inputs and the expected outputs. The second section contains three iterative loops, with appropriate read and write statements, to do the actual computation.

This program has been designed to produce output such as shown in Appendix A and to provide g(t), g(x), ϕ.g(t), or cumulative ϕ.g(x). In general, this output is an attempt to characterize the fallout pattern by describing several isodose rate contours in terms of upwind length, downwind length, maximum width, and downwind distance to maximum width. Also included is the maximum D_{H+1} at ground zero. The required inputs in order are:

FFRAC = Real number specifying fission fraction for burst.

IYIELD = Integer parameter specifying the number of yields to be evaluated.

ISHEAR = Integer specifying the number of shear conditions.

IWIND = Integer specifying the number of wind conditions.

IGT	=	Integer specifying output including G(T) and time. If desired enter "1", if not enter "0".
IGX	=	Integer requesting output of G(X) and downwind distance. If desired enter "1", if not enter "0".
ICUMGX	=	Integer requesting cumulative G(X) for each input dose rate condition. If desired enter "1", if not enter "0".
XLEN	=	Real number specifying the downwind and upwind marching interval. The units are nautical miles.
INT	=	Integer specifying which iteration the write statements for G(X) and G(T) act upon. I.E., if INT = 10 then every tenth value of G(X)/G(T) and distance/time will be printed.
YIELD	=	Real number specifying the yield of the weapon in megatons.
WIND	=	Real number specifying the effective wind in knots.
SHEARY	=	Real number specifying the crosswind shear component in knots/kilofeet.
DHI	=	Real number specifying the D_{H+1} the computer will use as it generates the output parameters.

The entire program including the subroutine Dose is in the form of a computer card deck. The above input parameters are read into the computer via standard unformatted read statements. Adhering to common Fortran procedure, the input parameters are coded onto data cards located immediately behind the second multipunch card (also called an End of Record Card) in the computer deck which separates the source program from the data. The information on each card begins in column one as either a real or integer number. Should multiple inputs be placed on one card, commas separate the individual parameters. The following list of data cards indicate the organization of the input data to produce results such as shown in Appendix B for a one yield, wind and shear condition:

Card 1: FFRAC

Card 2: IYIELD,ISHEAR,IWIND,IGT,IGX,ICUMGX

Card 3: XLEN,INT

Card 4: YIELD

Card 5: SHEARY

Card 6: WIND

Cards 7-15: DHI*

Additional data cards will be necessary if IYIELD,ISHEAR, or IWIND is greater than one.

The output of the program will repeat many input parameters along with the specified output. The output is:

*Note that this program is designed to produce output such as shown in Appendix B for eight dose rate contours.

INITIAL CONDITIONS	=	yield, effective wind, shear, fission fraction and step size.
G(X)	=	Fractional deposition rate of fallout per linear mile. The units are per nautical mile. Also included is corresponding distance from ground zero.
G(T)	=	Fractional deposition rate of fallout per unit time. The units are per hour. Accompanying G(T) is its time coordinate in hours.
DWDMAX	=	Distance in nautical miles from ground zero downwind to the dose rate specified by DHI.
UPMAX	=	Greatest upwind dose rate specified by DHI from ground zero. The units are nautical miles. Note this value may be (-) or (+) depending on the magnitudes of the effective wind and yield.
DBMAX	=	Maximum D_{H+1} on the hotline contained within the total fallout pattern specified by the minimum DHI. The units are Roentgens/hour.
RMAXD	=	Distance from ground zero in nautical miles to DBMAX.
DGZ	=	The D_{H+1} (Roentgens/hour) at ground zero.
YYMAX	=	Maximum crossrange width in nautical miles of iso-dose rate contour specified by DHI.

R2MAXW = Downwind or upwind distance to YYMAX. Units are nautical miles.

CUMGX = Cumulative G(X) bounded by the upwind and downwind range data specified by DHI. CUMGX calculated by trapezoidal integration and is dimensionless.

The second section of the main program contains three DO-Loops which compute via subroutine Dose those parameters listed in the output. The first DO-Loop begins at ground zero and marches downwind along the hotline calling Dose at each location via the call statement on page (97). The parameters DWDMAX, G(X), or G(T), RMAXD, DGZ, and CUMGX are computed for each location. The parameter DWDMAX is compared with the value determined from the previous iteration. The maximum DWDMAX and corresponding RMAXD are stored for further comparison and/or output. The second DO-Loop repeats the above process in the upwind direction. Cumulative $\phi.g(x)$ is computed by trapezoidal integration over the pattern. The third DO-Loop marches downwind along the hotline from ground zero computing DBMAX and R2MAXW using the subroutine call mentioned on page (98). The parameter DBMAX and corresponding R2MAXD are compared between iterations. Maximum DBMAX and R2MAXD is stored for further comparison and/or output. In all cases, the length of the iteration varies according to input step size and D_{H+1} contour defining the limits of the pattern.

As a final note, it is also necessary to preface the WSEG source program with several control cards in order for the computer to compile and execute the program properly. Like the data cards discussed earlier, the information is coded beginning in column one of each card. The following control cards represent the minimum required to successfully run the program.

The first control card is the Job card containing a three letter identifier, system preference, computer memory requirement, computer access number, and for AFIT students, last name and box number. The second control card executes the Fortran compiler. The third control card executes the binary program generated by the Fortran compiler. The final control card is a multipunched *End of Record* card which separates the control cards from the source deck. The following is an example of the control cards including proper format:

Card 1: XXX,STANY,CM60000.T111111,DOE,0000

Card 2: FTN.

Card 3: LGO.

Card 4: (7/8/9)

VITA

Dan Warren Hanifen was born on 28 November 1952 in Denver, Colorado, the son of Dan E. Hanifen and Dorilda T. Hanifen. He graduated from high school in Baltimore, Maryland in 1971. In June of 1975 he graduated from the United States Air Force Academy with a Bachelor of Science in Engineering Science. He was then assigned to Vandenberg A.F.B. where he was involved in the field testing and launch of several Advanced Ballistic Reentry Vehicles. In August of 1978 he entered the Graduate Nuclear Engineering program at the School of Engineering, Air Force Institute of Technology.

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The purpose of this independent study is to recreate and document the most popular analytical fallout model in use over the past twenty years, WSEG-10. Local access to WSEG-10 at the Air Force Institute of Technology, School of Engineering, will provide a basis for future fallout studies. As such, this study provides a fully documented Fortran computer code containing the most recent version of the WSEG-10 analytical model with sample output. To further understand this computer code, a general discussion of

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the WSEG-10 fallout model and analysis of crossrange dispersion (σ_y) and activity conservation is included. Results of the analysis of σ_y demonstrate that diffusive growth is not accounted for in the model and that crosswind shear is the dominant, long term effect. In a comparative conservation analysis, the WSEG model in use today does not conserve activity due to the unnormalized character of the crossrange transport function. This effect is substantial at yields less than .1 MT. Activity not conserved varied between 31.4% at 1 KT and a wind of 60 st.mi. to less than 1% at 100 MT and winds of 60 st.mi. Also included is a further discussion of model limitations or inconsistencies discovered either through computer use during this independent study or during initial literature search.